

A. G. Contract No. KR93 1973TRN
ECS File: JPA 94-12
JPA File: 93-112*
Project: P4293 57P
Section: RHODES-ITMS Project Ph. I

INTERAGENCY AGREEMENT
BETWEEN
THE ARIZONA DEPARTMENT OF TRANSPORTATION
AND
THE ARIZONA BOARD OF REGENTS
ACTING FOR AND ON BEHALF OF
THE UNIVERSITY OF ARIZONA

THIS AGREEMENT is entered into 13 December, 1993,
between agencies of the State of Arizona, to wit; the ARIZONA
DEPARTMENT OF TRANSPORTATION, acting through its HIGHWAYS
DIVISION (the "ADOT") and the UNIVERSITY OF ARIZONA, acting
through its BOARD OF REGENTS (the "U of A").

I. RECITALS

1. The ADOT is empowered by Arizona Revised Statutes
Section 28-108 and 28-112 to enter into this agreement and has
by resolution, a copy of which is attached hereto and made a
part hereof, resolved to enter into this agreement and has
delegated to the undersigned the authority to execute this
agreement on behalf of the ADOT.

2. The U of A is empowered by Arizona Revised Statutes
Section 15-1625 to enter into this agreement and has by
resolution, a copy of which is attached hereto and made a part
hereof, resolved to enter into this agreement and has
authorized the undersigned to execute this agreement on behalf
of the U of A.

3. The Federal Highway Administration has encouraged
research and development of the national Intelligent Vehicle
Highway System (IVHS) and the various components thereof, to
address the future needs of the national and urban highway
transportation system. Research funds have been made available
for the State to undertake and continue IVHS and other types of
transportation research. This agreement is to define the
terms and conditions of the research and the financing thereof.

THEREFORE, in consideration of the mutual agreements expressed
herein, it is agreed as follows:

| |
|--|
| NO. <u>18265</u> |
| FILED WITH SECRETARY OF STATE |
| Date Filed <u>12/13/93</u> |
| <u>Richard Mahoney</u> Secretary of State |
| By <u>Vicky J. Graenewald</u> |

II. SCOPE

1. The ADOT will:

Provide the U of A research funds in the amount of \$150,000.00, on a monthly cost reimbursement basis for activities performed directly relating to the research, in strict accordance with Attachment A, which is attached hereto, incorporated herein and made a part hereof.

2. The U of A will:

a. Apply funding to the research and development activities in strict accordance with Attachment A and all applicable statutes, laws, rules and regulations.

b. Invoice the ADOT for reimbursements no more often than monthly, supported by narrative reports and data compliant with Section IV.3 of Attachment A, in a total amount not to exceed \$150,000.00.

III. MISCELLANEOUS PROVISIONS

1. Should the work contemplated under this agreement be completed at a lower cost than the reimbursed amount, or for any other reason should any of these funds not be expended, a proportionate amount of the funds provided shall be reimbursed to the ADOT.

2. This agreement shall remain in force and effect until completion of said activities and reimbursements; provided, however, that this agreement may be cancelled at any time prior to the commencement of performance, upon thirty (30) days written notice to the other party.

3. This agreement shall become effective upon filing with the Secretary of State.

4. This agreement may be cancelled in accordance with Arizona Revised Statutes Section 38-511.

5. The provisions of Arizona Revised Statutes Section 35-214 are applicable to this contract.

6. In the event of any controversy which may arise out of this agreement, the parties hereto agree to abide by required arbitration as is set forth in Arizona Revised Statutes Section 12-1518.

8. All notices or demands upon any party relating to this agreement shall be in writing and shall be delivered in person or sent by mail addressed as follows:

Arizona Department of Transportation
Joint Project Administration
205 South 17 Avenue, Room 222E Mail Drop 616E
Phoenix, AZ 85007

The University of Arizona
Systems and Industrial Engineering Department
College of Engineering and Mines
Tucson, AZ 85721

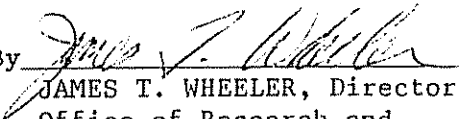
9. Attached hereto and incorporated herein is the written determination of legal counsel that the parties are authorized under the laws of this State to enter into this agreement and that the agreement is in proper form.

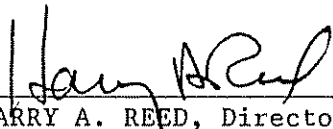
IN WITNESS WHEREOF, the parties have executed this agreement the day and year first above written.

STATE OF ARIZONA

ARIZONA BOARD OF REGENTS
THE UNIVERSITY OF ARIZONA

DEPARTMENT OF TRANSPORTATION

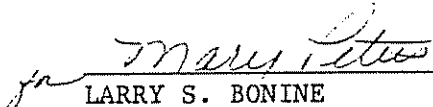
By 
JAMES T. WHEELER, Director
Office of Research and
Contract Analysis

By 
HARRY A. REED, Director
Transportation Planning

RESOLUTION

BE IT RESOLVED on this 10th day of August 1993, that I, the undersigned LARRY S. BONINE, as Director of the Arizona Department of Transportation, have determined that it is in the best interests of the State of Arizona that the Department of Transportation, acting by and through the Transportation Planning Division, to enter into an agreement with the University of Arizona for the purpose of defining responsibilities for conducting research relating to the Intelligent Vehicle Highway System and related components.

Therefore, authorization is hereby granted to draft said agreement which, upon completion, shall be submitted for approval and execution by the Director, Transportation Planning Division.



LARRY S. BONINE
Director

CERTIFICATION

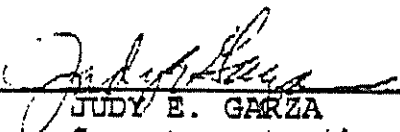
STATE OF ARIZONA)
)
County of Maricopa)

I, JUDY E. GARZA, the duly appointed, qualified and acting Secretary to the Arizona Board of Regents, do hereby certify that during a regular meeting of said Board held on April 1, 1991, the Board, by motion duly made, seconded and carried, approved and authorized the following:

Amended Board Policy 3-203, Research Contracts and Public Service Agreements, as attached, to permit the universities to approve all initial research and public service contracts that do not exceed \$1,000,000 and all continuation contracts that do not exceed \$1,500,000.

I further certify that said meeting was duly called and regularly convened and was attended throughout by a majority of the members of said Board, and that approval has not since been altered or rescinded.

IN WITNESS WHEREOF, I have hereunto set my hand and the Seal of said Board this 10th day of January, 1992.



JUDY E. GARZA
Secretary to the
Board of Regents

INTERGOVERNMENTAL AGREEMENT

DETERMINATION

AGENCY NAME: Arizona Department of Transportation

AWARD EFFECTIVE DATE: Upon filing with Secretary of State or
Pima County Recorder

TERMINATION DATE: 11/30/94

AMOUNT: \$150,000

PURPOSE: Real Time Traffic-adaptive Control for Integrated
Traffic Management of the I-17 Corridor

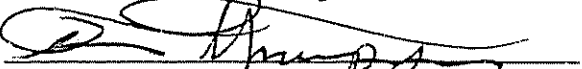
UNIVERSITY COLLEGE/DEPARTMENT: Systems and Industrial
Engineering

The undersigned has determined that the foregoing agreement is in proper form and is within the powers and authority granted under the laws of the State of Arizona to the Board of Regents.

Dated this ^{22nd} ~~19th~~ day of November, 1993.

Joel Sideman, Counsel
Arizona Board of Regents

By


Thomas M. Thompson



STATE OF ARIZONA

OFFICE OF THE ATTORNEY GENERAL

GRANT WOODS
ATTORNEY GENERAL

1275 WEST WASHINGTON, PHOENIX 85007-2926

MAIN PHONE : 542-5025
TELECOPIER : 542-4085

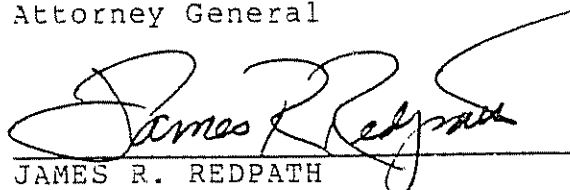
INTERGOVERNMENTAL AGREEMENT
DETERMINATION

A. G. Contract No. KR93-1973-TRN, an agreement between public agencies, has been reviewed pursuant to A.R.S. §11-952, as amended, by the undersigned Assistant Attorney General who has determined that it is in the proper form and is within the powers and authority granted to the State of Arizona.

No opinion is expressed as to the authority of the remaining parties, other than the State or its agencies, to enter into said agreement.

DATED this 8th day of December, 1993.

GRANT WOODS
Attorney General


JAMES R. REDPATH
Assistant Attorney General
Transportation Section

JRR:lsr
8290G

**REAL-TIME TRAFFIC-ADAPTIVE
CONTROL FOR INTEGRATED TRAFFIC
MANAGEMENT
OF THE I-17 CORRIDOR**

FOR

ARIZONA DEPARTMENT OF TRANSPORTATION

THE UNIVERSITY OF ARIZONA
DEPARTMENT OF SYSTEMS AND INDUSTRIAL ENGINEERING

JULY 1993

REAL-TIME TRAFFIC-ADAPTIVE CONTROL FOR INTEGRATED TRAFFIC MANAGEMENT OF THE I-17 CORRIDOR

PROPOSAL

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I. INTRODUCTION

L1 IVHS Overview

The Intelligent Vehicle Highway System (IVHS) program is a high technology approach to address the existing and future needs of the national highway and the urban transportation systems. IVHS is being developed through the participation of federal, state and local governments, industries, academic institutions, professional transportation societies and organizations, and the international automotive and electronic standard-setting organizations. The goal of the program is to develop, test and deploy advanced concepts and technologies in the areas of computers, communications, and navigation, for the eventual deployment of an Intelligent Vehicle Highway System.

The objective of IVHS is to obtain better system performance through the application of advanced computer, communication, and control technologies for enhancing the operational effectiveness and efficiency of the transportation system. IVHS seeks to apply these technologies to the solution of problems associated with surveillance, modeling, forecasting, information management, traffic control, and traveler/operator decision making. IVHS will address the needs of the total system including streets and highways, vehicles and travelers. Figure I-1 illustrates the basic functional components of IVHS.

Five principle components have been identified within IVHS. These components are:

- Advanced Traffic Management System (ATMS)
- Advanced Traveler Information System (ATIS)
- Commercial Vehicle Operations (CVO)
- Advanced Public Transportation System (APTS)
- Advanced Vehicle Control System (AVCS).

The ATMS provides the backbone for IVHS. It provides the surveillance, communication, and computation for the traffic management system which includes a traffic management center, advanced surveillance and detection, real-time traffic-adaptive signal control, driver route advising, incident detection and management, and operator decision support.

The ATIS is responsible for communicating information to the travelers to assist in trip, mode and route planning. It will assist travelers in the selection the "best" mode of travel, the "best" route, and will assist drivers in finding parking facilities and specific addresses. It will provide the other IVHS components with information about travelers, including information such as location, mode, origin/destination and route.

The CVO system addresses the special needs of the commercial users of the transportation system. It includes automatic vehicle identification, weigh-in-motion, automatic toll and fee collection, safety monitoring, fleet management and regulation enforcement.

The APTS provides up-to-date information on transit system operation including service schedule, location of transit vehicles and available services. It coordinates with the ATMS and ATIS to provide alternative travel modes for efficient and effective use of transportation facilities.

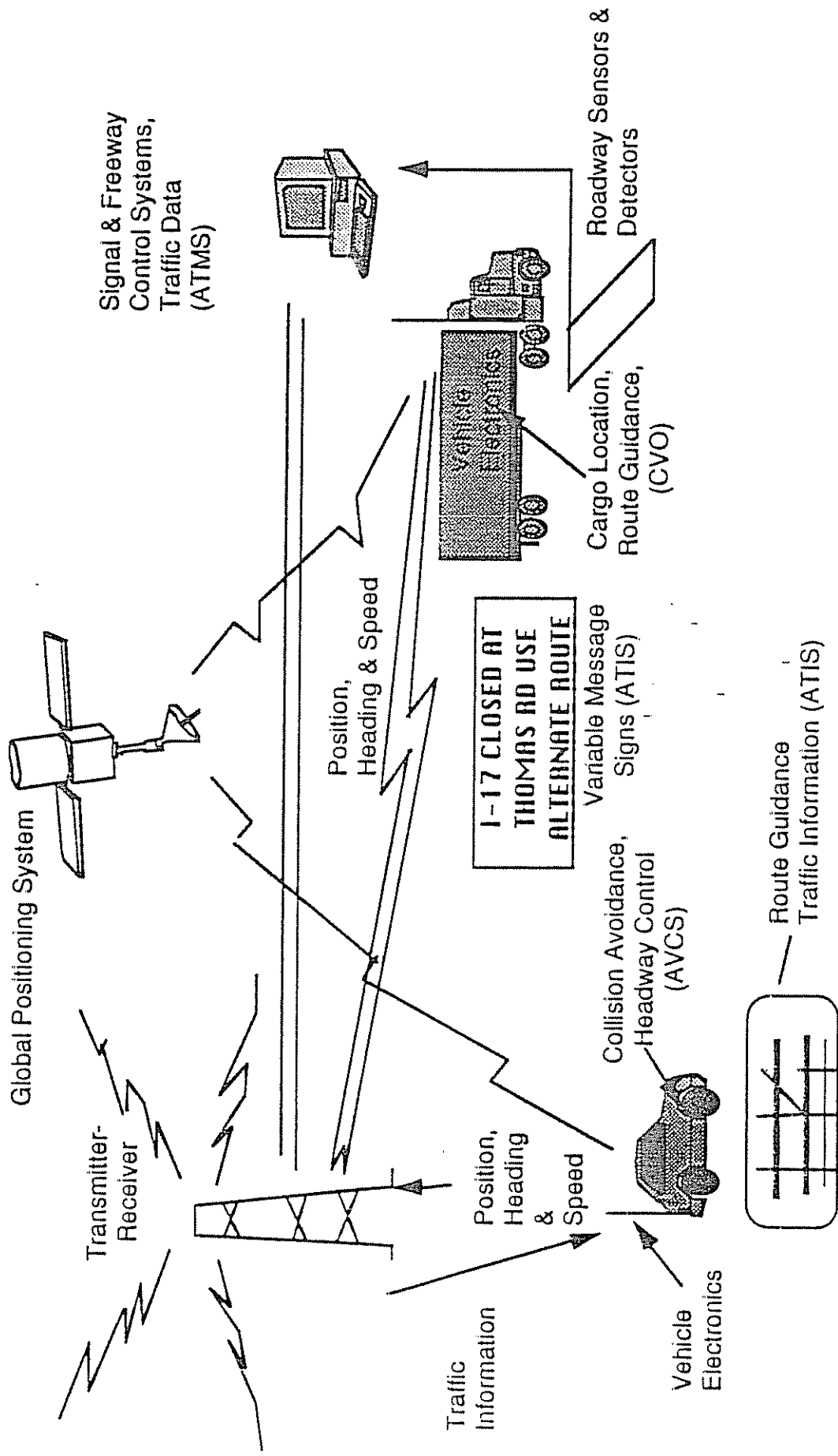


Figure 2-1-1. Functional Components of the IVHS.

The AVCS provides technologies for automated highways through advanced guidance and collision avoidance systems including intelligent cruise control for automatic platooning of vehicles traveling at high speeds on the highways. AVCS is the most "futuristic" component of the IVHS.

L2 ATMS Overview - FHWA Projects

ATMS is the backbone for IVHS. It includes surveillance and detection data collection, communication, monitoring, and control functions of traffic management, as well as the interface between the other IVHS components. It's goal is to provide adaptive transportation management systems and control strategies to achieve maximum transportation efficiency. The ATMS is composed of five components¹:

- Advanced Surveillance and Detection System
- Real-time Traffic-adaptive Signal Control System
- Incident Detection and Management System
- Route Guidance Information System
- IVHS Component Integration System.

The advanced surveillance and detection system is the traffic information collection system within ATMS. New technologies including video image processing, infrared, sonar and magnetic detectors, may provide more accurate and reliable data collection than the traditional inductive loop detector technology, although it is anticipated that loop technology will provide the majority of the data collection function in the near future. Issues in the design and development of advanced surveillance and detection systems include (1) detector accuracy and reliability in a wide variety of operating environments, (2) types and frequency of information availability, and (3) the location of detectors for optimal traffic observation and forecasting.

The real-time traffic-adaptive signal control system will provide reactive and proactive control of traffic. It will manage both recurrent and non-recurrent congestion as well as non-congested traffic situations. Existing real-time traffic control systems include SCOOT, SCATS, TRAC, PROLYN, UTOPIA and CTCS². While these systems provide traffic responsive surface street signal control, none of them provide proactive control nor integrated freeway/surface street control. (*This proposal addresses this issue*).

The incident detection and management system is responsible for detecting incidents that effect the performance of the traffic network and developing an effective management strategy to: (1) control the traffic congestion that can occur due to the incident; and (2) dispatch the appropriate emergency teams to "remove" the incident.

¹ Santiago, A., H. Chen and A. Kanaan. "ATMS: What it Can Accomplish," presented at the Second International Conference on Applications of Advanced Technologies in Transportation Engineering, Minneapolis, Minnesota, August 1991.

² see Mirchandani, Head and Sheppard. "A Hierarchical IVHS-ATMS Structure for Real-Time Traffic Control," presented at the ISATA Conference, Florence, Italy, June 1992 for a review of these systems.

The route guidance information system provides drivers with real-time traffic information on which they can base their decisions on route selection, departure times, and detours. The route guidance system can be implemented using variable message signs (VMS), highway advisory radio (HAR) or through an ATIS system via in-vehicle displays and information services.

The IVHS component integration system is responsible for communicating information between the ATMS and other IVHS components to facilitate the system-wide management of traffic through the operation of the Intelligent Vehicle Highway System.

L3 FHWA Research and Demonstration Projects

To facilitate the development of the ATMS, the Federal Highway Administration (FHWA) is focusing on several key elements including:

- Detection Technologies for IVHS
- Real-time Traffic-adaptive Signal Control for IVHS
- Network-wide Optimization
- Support Systems for ATMS
- Incident Detection and Management Systems
- Integration of ATMS with other IVHS Programs
- Human Factors in ATMS Design Evolution
- Traffic Models for Testing Real-time Signal Control Logic
- ATMS Communication Standards
- Strategies for Integrated Freeway/Arterial Control.

These key elements will provide the fundamental building blocks for future ATMS. Figure I-2 shows the relationships between these studies. Currently, FHWA has ongoing research programs, is in the process of proposal evaluation, or is planning research programs to address each of these key elements. This proposal addresses the area of Real-time Traffic-adaptive Signal Control for integrated freeway and surface street systems.

FHWA is either sponsoring or planning to sponsor several other IVHS research projects in the areas of ATIS, APTS, AVCS, and CVO. A list of these are given in the FHWA report: *Intelligent Vehicle Highway System (IVHS) Projects in the United States*, May 1992

FHWA has also initiated several demonstration projects. These projects are classified as IVHS Operational Tests and IVHS Deployment Projects. IVHS Operational Tests serve as the transition between R&D and full scale deployment. IVHS Deployment projects are intended to facilitate accelerated deployment of ATMS and ATIS systems and to lay the foundation for future IVHS systems. Operational test projects in the ATMS area include:

- Connecticut Freeway ATMS, Hartford, Connecticut - included in the project are a statewide freeway surveillance and control program aimed at evaluating the use of roadside mounted radar and CCTV for incident detection and verification.

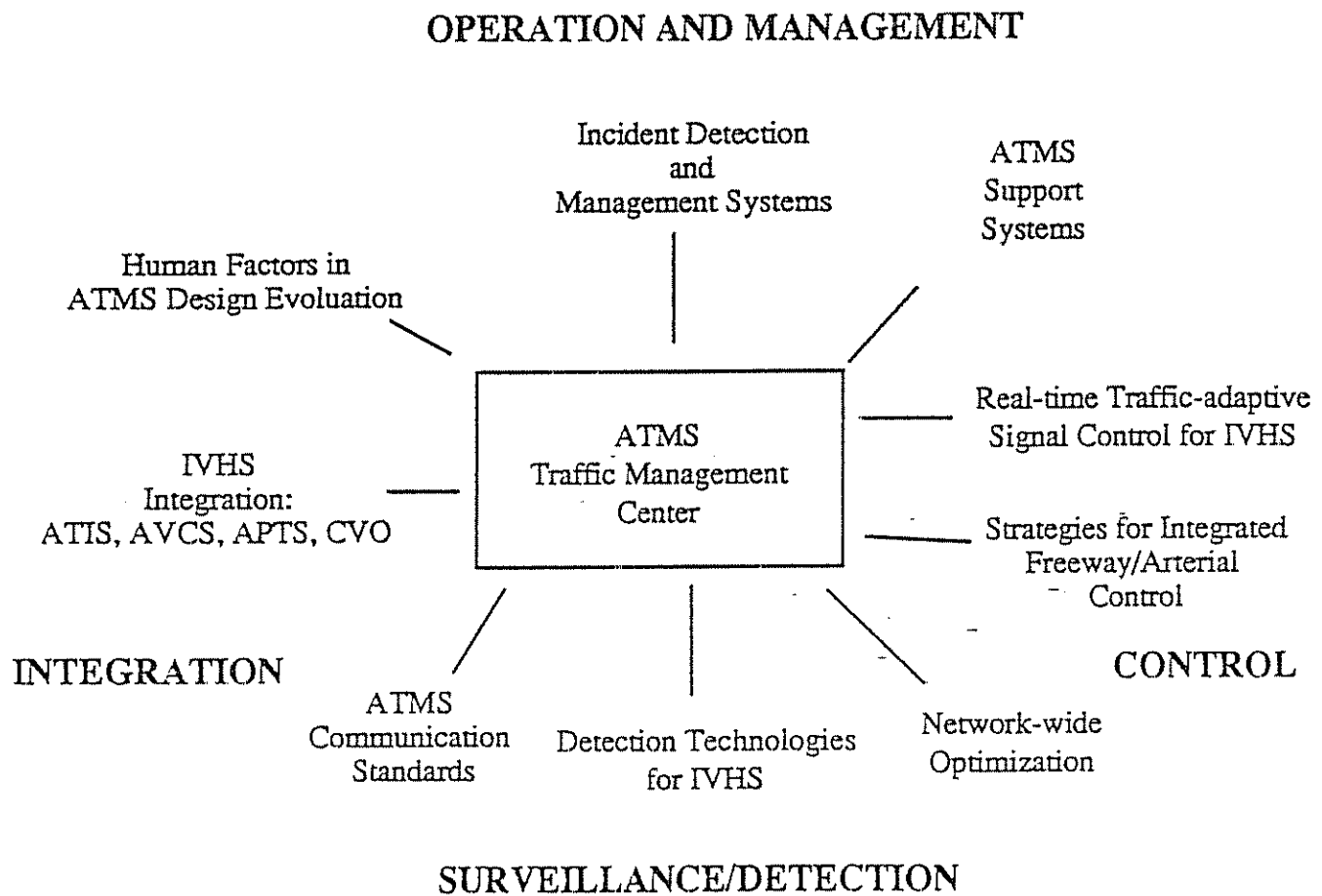


Figure I-2. Ongoing and Planned FHWA R&D Efforts.

- GuideStar, Minnesota - included in the project are the integration of a number of on-going operational ATMS/ATIS efforts designed to reduce congestion and improve safety. The program emphasizes the gathering and distribution of traffic information for use by traffic managers and motorists. The program uses video detection (Autoscope).
- INFORM, Long Island, NY - this project integrates surveillance and control of three freeways with adjacent cross street and selected parallel arterial streets, to facilitate corridor flow. The freeway and surface street surveillance and control is monitored at a Traffic Information Center.
- MAGIC - this system will be designed to divert motorist from congested or areas to alternative routes over a nine county region of New Jersey.
- Maryland Arterials & Baltimore/Washington Parkway - this study proposes a comprehensive feasibility study for future traffic management and communications technologies including information dissemination using commercial television, automatic incident detection and incident management plans.
- Multi-jurisdictional Live Aerial Video, Fairfax Co., VA. and Montgomery County MD - these project are for testing live aerial video for transmission back to traffic management centers, for use in incident detection and traffic management.
- Satellite Communications Feasibility Study, Philadelphia - this study is investigating the use of satellite communication for the transmission of surveillance and control information including loop detector data, VMS messages, and CCTV signals.
- SMART, Los Angeles, CA - this project uses advanced technologies such as Highway Advisory Radio (HAR), Changeable Message Signs (CMS), kiosks and teletext to (1) advise travelers of current traffic conditions and alternate routes, (2) improve emergency response and (3) provide coordinated interagency traffic management using voice communication and electronic data sharing between the operations centers for the freeways (Caltrans) and the streets (cities).
- Toll Road ETTM, NJ - this project focuses on electronic toll and traffic management (ETTM) using "electronic tags" in the windshield of vehicles that can be used at any toll facility.
- TRANSCOM, Northern New Jersey and Metropolitan New York area - this project uses 1000 commercial vehicles equipped with AVI transponders. Electronic readers are located at several toll booths for automatic toll collection as well as at other locations allowing these vehicles to act as traffic probes. The data, including travel times, speed and incident occurrence, will be collected to evaluate this method of data collection.

- Urban Congestion Alleviation, Northern Virginia- this project will test and evaluate the performance and reliability of Video Image Detection System (VIDS) technology in detecting traffic flow and freeway incidents.

Operational test projects in the ATIS area include:

- ADVANCE - this project will equip up to 5000 vehicles in the northwestern suburbs of Chicago with in-vehicle navigation and route guidance systems. The vehicles will serve as probes to collect real-time traffic information.
- DIRECT, 21 miles of the I-94 corridor in Detroit, MI - this project will deploy and evaluate four alternative low cost methods of communicating advisory information to motorists including Radio Data Systems (RDS), Automatic Highway Advisory Radio (AHAR), Highway Advisory Radio (HAR) using AM frequency band, and cellular telephone.
- FAST-TRAC, Oakland County, MI - this system will integrate ATMS and ATIS for surface streets using existing advanced technologies including the SCATS real-time traffic control system, the Autoscope detection system, and the Ali-Scout route guidance system. Vehicles will serve as probes to collect real-time traffic information using infrared communication between the vehicle and road side beacons.
- In-Vehicle Signing and Variable Speed Limit - this project will use variable speed limit signs, variable message signs and in-vehicle communication equipment to improve the safety of a 40-mile stretch of I-90 across the Snoqualmie Pass in Washington State, a rural area subject to extreme weather conditions.
- Pathfinder, Los Angeles, CA - this project cooperates with the SMART corridor project by providing in-vehicle navigation information to drivers of 25 specially equipped vehicles about accidents, congestion, highway construction, and alternative routes using an electronic map.
- TravTrek, Orlando, FL - this system provides traffic congestion information and motorist "yellow pages" information, tourist information and route guidance to operators of 100 test vehicles.
- Urban Congestion Alleviation, Baltimore - this project incorporates variable message signs (VMS) information and Traffic Advisory Radio (TAR) to motorists approaching the city of Baltimore with accurate and timely information from a variety of sources including police, maintenance personnel and toll road operators.

Operational test projects in CVO include:

- Advantage I-75, Florida, Georgia, Kentucky, Tennessee, Ohio, Michigan, Ontario and Quebec - this project will facilitate motor-carrier operations by allowing transponder equipped and properly documented trucks to travel any segment along I-75 at mainline speeds with minimal stopping at weigh/inspection stations.
- HELP/Crescent, British Columbia, Washington, Oregon, California, Arizona, New Mexico and Texas - this project integrates Automatic Vehicle Identification (AVI), Automatic Vehicle Classification (AVC) and Weigh-in-Motion (WIM) technologies to automate the regulatory, weight enforcement and fleet management functions of commercial vehicle operation.

IVHS deployment projects in the ATMS area include:

- Advanced Traffic Management Systems Model Study for the Denver Metropolitan Area - this project is a 10-year effort aimed at implementing IVHS technology to mitigate congestion and improve air quality through ATMS.
- Advanced Traffic Management Systems Model Study for the Portland Metropolitan Area - this project is aimed at providing direction for the design of area-wide advanced traffic management systems, including a freeway operations center, to develop a multi-jurisdictional incident management program and to address the institutional issues related to the deployment of ATMS programs.
- Incident Management, Minneapolis-St. Paul - this project uses HAR to send information to motorists so they can assess current driving conditions and take alternative routes when a major incident occurs and to implement a Heavy Truck Incident Management effort to develop strategies to reduce and respond to heavy truck incidents.
- Incident Management, Seattle - this project is part of the Freeway and Arterial Management Effort (FAME) and is to develop a framework for establishing and implementing an incident management system.
- Integrated Systems Project, Anaheim - this project integrates an inter-jurisdictional traffic management approach for special events occurring in Anaheim and Orange County using a computerized traffic signal system, Highway Advisory Radio (HAR), Closed-Circuit Television (CCTV) and Changeable Message Signs (CMS) to monitor and coordinate traffic. The system is electronically integrated with the Caltrans traffic operations center.
- Integrated Systems, Seattle - this project is part of the Freeway and Arterial Management Effort (FAME) that will demonstrate the benefit of an integrated system by designing and implementing a control system that automatically modifies arterial timings in response to freeway conditions and modification of ramp meter rates based on arterial conditions.

The proposed ITMS concept includes many features addressed in several of the above demonstration projects. However, the integration of route guidance and real-time traffic control for both advising drivers and for the development of appropriate traffic controls has not been addressed in these projects. The FAST-TRAC project includes both real-time control and route advising, but only for providing drivers with route advisories; these advisories are not used for traffic control. The ITMS concept presented in this proposal provides an important step in fully utilizing available IVHS information and developing a truly real-time traffic adaptive ITMS.

L4 Proposed Project Goals

This proposal addresses the research and development of a real-time traffic-adaptive signal control system, for an integrated freeway/surface street environment for the I-17 corridor. The concept on which this proposal is based has been developed over the past year as part of the RHODES research program. The RHODES research program has addressed the design of a real-time traffic-adaptive signal control system for only a surface street network. In Section III of this proposal, the hierarchical control concept of RHODES is extended to include the integrated control of freeways and surface streets.

- The goal of this proposed project is to apply the experience and results attained in the past year on the RHODES research project to the related traffic control problem of integrated freeway/surface street control. Specifically, we will develop control algorithms for freeway/surface street interchanges and demonstrate and evaluate these algorithms using a computer simulation of actual conditions on the I-17 corridor.

The products of this research will include:

- a series of working papers detailing efforts on the various tasks including:
 - a review of freeway and corridor models, both mathematical models and computer simulations,
 - a review and evaluation of freeway and integrated street/freeway control methods and algorithms,
 - an evaluation of freeway and corridor simulation models in terms of their applicability to the laboratory evaluation of real-time traffic-adaptive control logic,
 - a case study report detailing the use of a freeway simulation model to evaluate the effectiveness of HOV lanes,
 - the formulation and development of the "Interchange Scheduler", "Interchange Dispatcher" and the "Intersection/Interchange Control Coordinator" (these systems are explained in Section III),
 - the formulation and development of the "Network Coordinator" model,

- a description of the demonstration of the integrated control models,
 - the results of the laboratory testing, including the test plan and a description of the test network (within the I-17 corridor),
-
- Enhanced freeway and enhanced integrated freeway/street simulation models³.
 - The data base and simulation package used to perform the freeway HOV lane case study.
 - The algorithm and computer implementation of the interchange scheduler.
 - The algorithm and computer implementation of the interchange dispatcher.
 - The algorithm and computer implementation of the intersection/interchange coordinator.
 - The algorithm and computer implementation of the network coordinator model.
 - A demonstration, or series of demonstrations, illustrating the operation of the component models both operating independently and in an integrated fashion.
 - A technical presentation of the models, algorithms, laboratory tests and the test results.

In addition, the results of this research effort will be submitted as papers and presentations to various professional organizations, journals and conferences. Another important product of this effort is the students that work as research assistants. Upon completion of their degree requirements these students would have gained valuable experience in the field of transportation and traffic engineering and may choose to pursue careers as transportation professionals.

³Currently the RHODES research team has been given permission, by the Federal Highway Administration, to use and modify the TRAF-NETSIM model. We will seek permission, from FHWA, to deliver a copy of the modified models to ADOT.

II. PHOENIX/I-17 CORRIDOR

A long-term goal of the Arizona Department of Transportation (ADOT) is to include IVHS technologies in the I-17 corridor to improve traffic conditions. The current short-term improvement plans for the corridor include only the construction of increased capacity. Longer term plans call for a Freeway Management System that includes I-17, but specific plans have not been formalized. The opportunity to incorporate an ATMS real-time traffic-adaptive signal control system with other IVHS technologies to address the traffic management needs of the corridor is complementary to ADOT's goals.

The I-17 corridor of interest extends from Thomas Road on the south to Thunderbird Road on the north and from 43rd Avenue on the west to 7th Avenue on the east. Figure II-2 shows a map of the corridor.

In 1986, JHK & Associates conducted a long-range planning study for the I-10 and I-17 corridors that extend approximately 50 miles through the Phoenix Metropolitan Area. Figure II-1 shows the freeway's 1985 freeway average daily traffic (ADT) volumes (and in parenthesis the volumes forecasted for year 2005) and the 1991 ADT volumes at the freeway corridor boundaries at Thomas Road and Thunderbird Road. The forecasts for year 2005 were made using the MAG 2005-34 transportation planning model. JHK's study recommends freeway widening, frontage road upgrades, half-mile crossings, park-and-ride lots and improved surveillance and control systems.

The ADOT Freeway Management System (FMS) is currently in the implementation phase including the construction of the control center building, installation of control center equipment, and the installation of field equipment on some freeway segments. Real-time traffic management, as proposed here, is not part of the current implementation. Future plans for the FMS include incident detection and management, variable message signs to report traffic conditions on the freeway, highway advisory radio reports and automatic dissemination of traffic information to ADOT personnel, the media, and the public -- in text, graphic and voice formats. This effort is being completed under a contract with Kimley-Horn & Associates.

The real-time traffic-adaptive ITMS concept presented in Section III of this proposal represents a potential application of IVHS technologies to the I-17 corridor. Preliminary design of this system will be based on data and simulation models of the I-17 corridor. This will help to ensure that the ITMS will meet the traffic management needs of the corridor.

When implemented the ITMS system will (1) provide adaptive control of ramp metering, (2) integrated control of interchange signals, (3) lane control, (4) speed and route advisories. Conceptually, one can envision the following IVHS technologies within the corridor: interchange traffic signal control that adapts in real-time to the traffic demand; and variable message signs (VMS) and highway advisory radio (HAR) to notify drivers, both on the freeway and on the street network, of travel conditions on the network. For example, a driver on the street network may be planning on using the freeway to reach a destination. A VMS could alert the driver of congested conditions on the freeway and can advise that one of the parallel arterials or the frontage roads be used instead. Driver

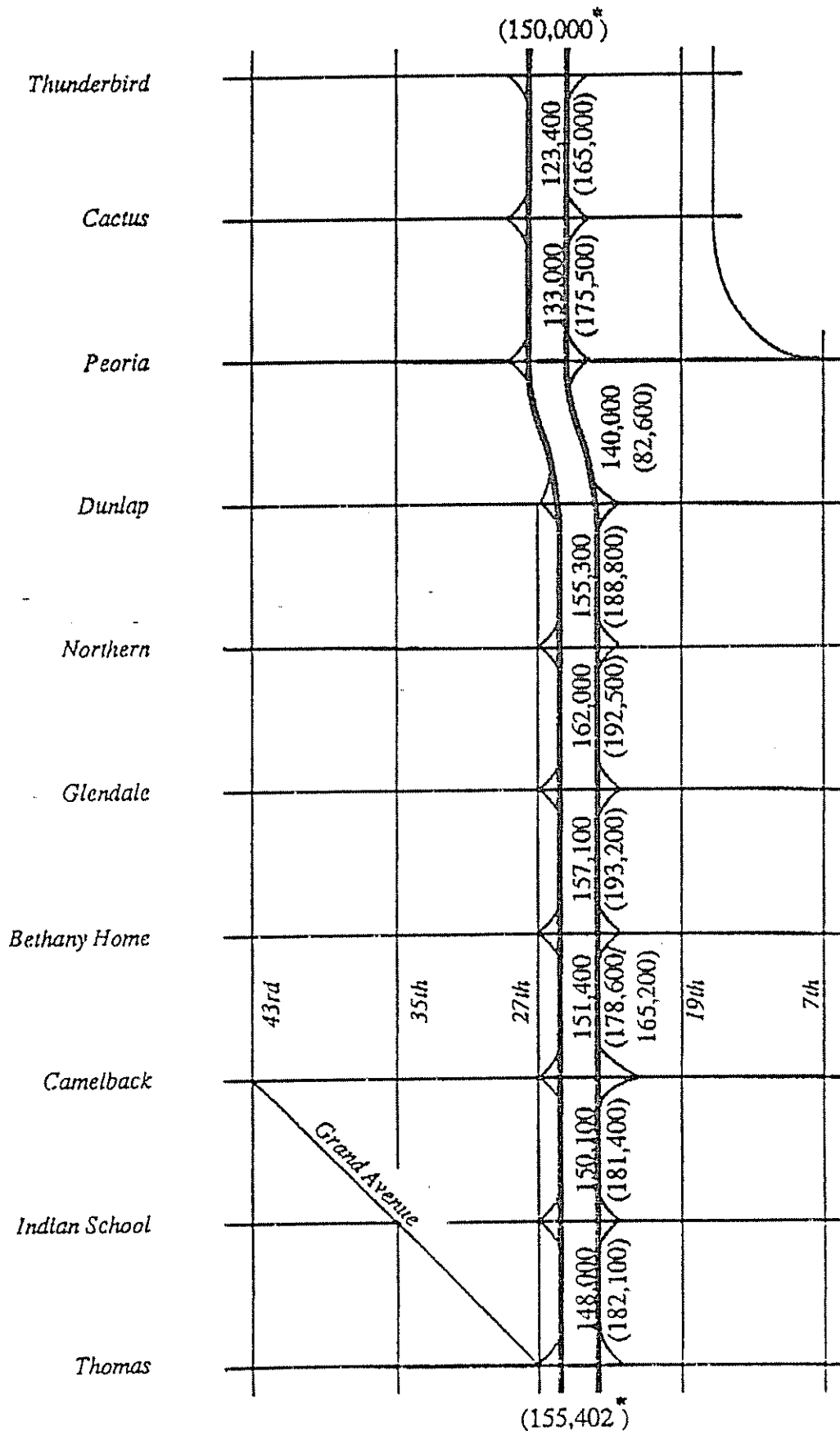


Figure II-1. 1-17 Corridor Numbers are 1986 ADT (2005 ADT). *1991 ADT.

notification prior to entering the freeway can greatly reduce freeway congestion and help the traffic control system to respond in a timely fashion. Other advisories may include routing drivers to the freeway instead of a congested arterial, or notifying drivers to use an upstream entry or exit ramp, or suggesting the use of another less-congested arterial. A key function in the operation of the proposed ITMS is the integration of driver advisories and real-time traffic-adaptive control.

II.1 National IVHS Corridor Demonstration Projects

A potential source of funding for the field implementation and evaluation of the ITMS concept presented in this proposal is the national IVHS Field Operational Test Program. The purpose of the operational tests is to integrate existing technology, research and development products, institutional and regulatory arrangements, as well as new technologies and new financial elements, into a real-world operational test bed under "live" transportation conditions. These operational tests serve as a transition between research and development and full deployment of IVHS technologies.

The program areas for the demonstration projects include:

- Systems that include direct benefit to travelers in rural areas,
- Advanced traveler information systems,
- Advanced traffic management systems,
- Alternative surveillance and detection systems,
- Environmental and roadway conditions sensor systems,
- Systems for commercial vehicles, and
- Advanced vehicle control systems.

The ITMS concept presented in this proposal represents research and development in the area of advanced traffic management systems. Together with the ADOT's freeway management system, which includes new technologies, our real-time traffic-adaptive control system should form a promising viable IVHS-ATMS concept for a corridor demonstration project.

(The development of a proposal for the IVHS Field Operational Test Program must be a concerted effort between all of the agencies involved. Since it focuses on an operational test, it is most appropriate that the principal contractor should be an operating agency. The research team will assist in the development of such a proposal.)

III. ITMS CONCEPT OVERVIEW

In this section we present our design concept for the Integrated Traffic Management System (ITMS). The concept is based on the principle of responding to the *natural* stochastic characteristic of travel behavior, both temporal and spatial, that results from independent trip generations between spatially distributed origins and destinations, driver route selections, transit traffic, pedestrians, distribution and fluctuation of vehicle speeds, network events (accidents, road closures, etc.), and driver and vehicle characteristics (headway, speed, size, etc.). The spatial and temporal "response characteristics" of these stochastic sources are best describable on different time and distance scales. Generation of origin-destination trips and the response to long term network events such as road closures for construction evolve in time scales of days, weeks and months. Drivers and vehicles respond in time scales of minutes and seconds to events such as phase changes at traffic signals, short-term changes in travel speeds (e.g. congestion), pedestrian traffic, and queues at intersections. Together, all of these sources of stochasticity result in a complex stochastic system. A real-time traffic-adaptive signal control system must respond to the various stochastic events in the system with appropriate controls with appropriate "time constants".

The different time and distance scales of the natural stochastic travel behavior leads to a hierarchical structure for a real-time traffic-adaptive control system. Figure II-1 shows an aggregate three level hierarchy where each level responds at an appropriate time and distance scale and depicts the relationship between the hierarchical control system, the surveillance/detection system and the traffic observation and prediction system. The hierarchical control system effects the traffic network through traffic control devices, such as signals, ramp meters, lane usage signs, variable message signs, etc. The surveillance/detection system senses the traffic. It can consist of traditional loop detectors and/or detection/surveillance equipment based on new technologies such as infrared, sonar, video, etc. The traffic observation system processes the surveillance/detector data to estimate and predict traffic characteristics at each of the appropriate time and distance scales. This allows the hierarchical control system to be proactive (based predictions) and reactive (based on estimation).

At the highest level, the *loading* level, the long-term systems perspectives are considered. The control problem at this level is to model and predict the long-term (hours, days, weeks and months) travel demand trends. For example, a significant fraction of the "rush hour" traffic consists of daily commuters who, in general, follow the same route to and from work each day. This regular pattern of travel is highly predictable. However, if, for example, a road is closed for construction, or a bridge is destroyed by a flood, or an accident is disrupting traffic, then the affected travelers will change to new routes once they learn of the network disruption. The *loading model* at the highest level of the control structure attempts to predict this regular demand, as well as, the changes in demand that may occur as a result of traffic disruptions.

At this juncture it is appropriate to briefly review *traffic equilibrium* models (also referred to as *traffic assignment* models) since the loading model is somewhat based on the same assumptions. Basically, the models are developed on the principle that users of a *network at steady state* equilibrate, over time, to route choices such that any change in the chosen routes result in additional disutility. However, if the steady state conditions no longer prevail (e.g., due to a traffic disruption), questions arise on (1) What is the new traffic equilibrium? and

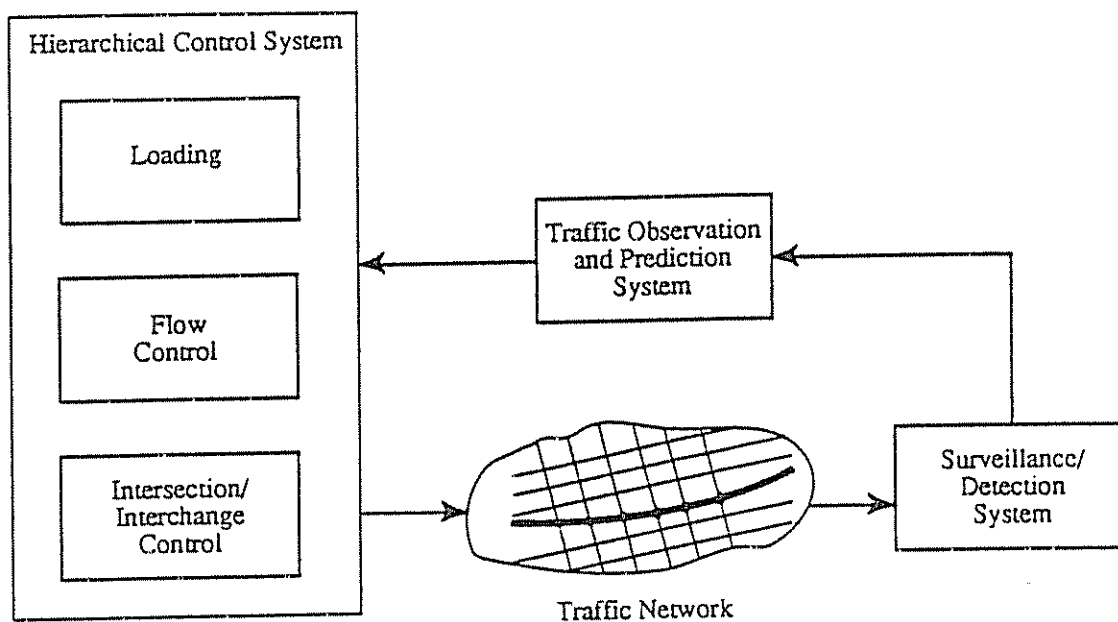


Figure III-1. Hierarchical control structure and relationship to surveillance/detection system and the traffic observation and prediction system.

(2) How long does it take to reach the traffic equilibrium? Answers to both these questions depend on what information is available to the users (VMS, traffic radio, ATIS, etc.) and how fast the information is available to the users. Supposedly, "*dynamic traffic assignment*" models are being developed to answer such questions, but so far nothing useful is available. The loading model being developed for the ITMS is a descriptive model that attempts to get approximate answers to the above questions.

Basically, using real-time detector counts at the inputs (origins) and outputs (destinations) on the boundaries of any subnetwork under control, the current subnetwork traffic conditions, and calibrated parameters, the loading model will predict approximate traffic loads on the subnetwork. Furthermore, using Bayesian statistical techniques, it is possible to continuously update "a priori" estimates of traffic loads based on current detector counts. It should be emphasized that at this level of the hierarchy only rough estimates of the traffic loads are necessary -- to be in the "ball park" so to speak -- since the actual control actions are ultimately decided at the lower hierarchical levels.

In addition to predicting travel demand, a calibrated loading model may also be useful for evaluating control related to lane usage, such as HOV lanes, reversible lanes, lane restrictions (e.g. no trucks in left most lanes, etc.), and HOV and transit priority at ramp meters. These controls effect the allocation of roadway facilities to meet travel demand and to implement the jurisdictional traffic control policies.

(We remark that, currently, *traffic equilibrium/assignment models* are used for the purposes of studying long-term travel demands and land use. They are

sometimes used for evaluating traffic effects of roadway improvements, zoning regulations and implementation of HOV and reversible lanes. However, such models have not been used for real-time traffic controls. Signal timing plans and ramp metering rates are normally determined off-line, using only observed traffic volumes for typical or average traffic demand. To accommodate varying demand over time, signal timing plans, ramp metering rates and lane usage strategies are typically implemented on a time-of-day basis.)

At the middle level, the *flow control* level, shorter time and distance scales are considered. At this level the time horizon is in terms of minutes, perhaps five to fifteen minutes. Generally the goal at this level is to provide smooth progressive traffic flow. On surface streets the goal may be arterial or route progression of platoons of vehicles; or coordination of signals to minimize stops, delay or air quality; or a composite function of these measures. On the freeway the goal may be to ensure smooth flow of vehicles including weave and capacity restrictions. Generally, the actions at the flow control level are based on average flow characteristics such as speed, density, average delay, number of stops, etc. For example, on surface streets these controls are currently determined using off-line packages such as MAXBAND, PASSER and TRANSYT. In real-time traffic adaptive signal control these off-line packages fail to respond to actual traffic demand, although the underlying principles of these packages may be made applicable to real-time control.

The lowest level, the *intersection/interchange control* level, considers the shortest time scales associated with the stochastics generated by individual vehicle characteristics, such as speed, headway, pedestrians, emergency vehicles, etc. At this level the control structure responds to the deviations from short-term average characteristics. For example, if the ramp metering rate was set to release five vehicles per minute and an unusually large number, say twelve, vehicles arrive at the ramp, the intersection/interchange controller may increase the release rate, within the allowable limits, to disperse the vehicles and prepare for the next platoon, or it may limit access to the ramp by skipping or shortening a phase (or phases) until the excess vehicles have been released.

This conceptual structure addresses the general characteristics of the traffic control problem at the three hierarchical levels associated with different time and distance scales. In the design of a real-time traffic-adaptive ITMS, the actual control and decision subsystems are not necessarily identical for freeways and surface arterial/street network (for brevity, we shall refer to this simply as "streets"). For example, the *flow control* problem for a freeway does not address the sequencing and timing of phases of a traffic signal, but addresses speed and merge controls. Also, the responsibility for freeway and street control is usually divided among different government agencies. Typically, the freeway control system is operated by a state or county, whereas the streets by a city. In the case where both the freeway and the streets are operated by a single agency, then either a highly integrated system or one that allows a higher priority for one or the other system will be most appropriate. For these reasons, it is important that the design of the ITMS is modular -- to allow cooperative and/or coordinated control of the integrated freeway/street system.

A requirement in the design of a modular ITMS is to decompose the integrated freeway control and the street control problem into two separate, but complementary subproblems, with a third coordinating subproblem responsible for ensuring proper communication and coordination between the two traffic

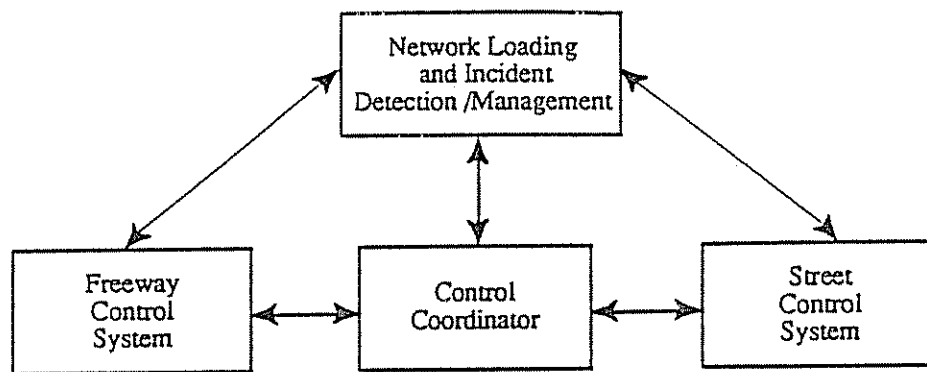


Figure III-2. Decomposition of ITMS into freeway control system (FCS), street control system (SCS), control coordinator and network loading and incident detection/management system.

control subsystems. Figure II-2 depicts this decomposition. The role of the control coordinator can be either active or passive. An active control coordinator would act to balance the optimization objectives of the two traffic control systems to achieve an overall level of performance that is better than that achievable by the two subsystems acting independently. A passive control coordinator would provide only information interchange between the two subsystems.

The incident detection and management system is responsible for detecting incidents such as accidents and disabled vehicles and then adjust the network loading model accordingly. For example, if an accident occurs on the freeway that severely restricts the capacity of the freeway, then the traffic on the freeway will divert to other routes. The network *loading* model will adjust the predicted loads based on the incident and observed loads to allow proper accommodation of the diverted traffic. The ability of the street control system to effectively and efficiently manage the increase in traffic demand due to freeway incidents is an important consideration in the design of a real-time traffic-adaptive signal control system. Other considerations for incident management such as dispatching emergency vehicles are not directly part of the real-time traffic-adaptive signal control system but are functions of the overall traffic management system.

III.1 Real-time Traffic-adaptive (Surface) Street Control Architecture

The hierarchical control architecture for the (surface) street control system (SCS) is shown in Figure II-3. The *street loading* component and the *route generation* component determine aggregate street traffic demands. The *street loading* component uses historical travel demand data, such as that used in transportation planning studies, and observed traffic trends to predict the street traffic loads over the next hour. These loads are the inputs to the *route generation* component that determines the routes and the volumes on these routes over the next 15-30 minutes using current source/sink volumes and travel speeds, as well as information on the freeway sources and sinks. If appropriate IVHS technologies are available, the route generation component can issue traveler advisories to assist drivers in avoiding congestion, hence suitably distributing the load to improve the traffic flow.

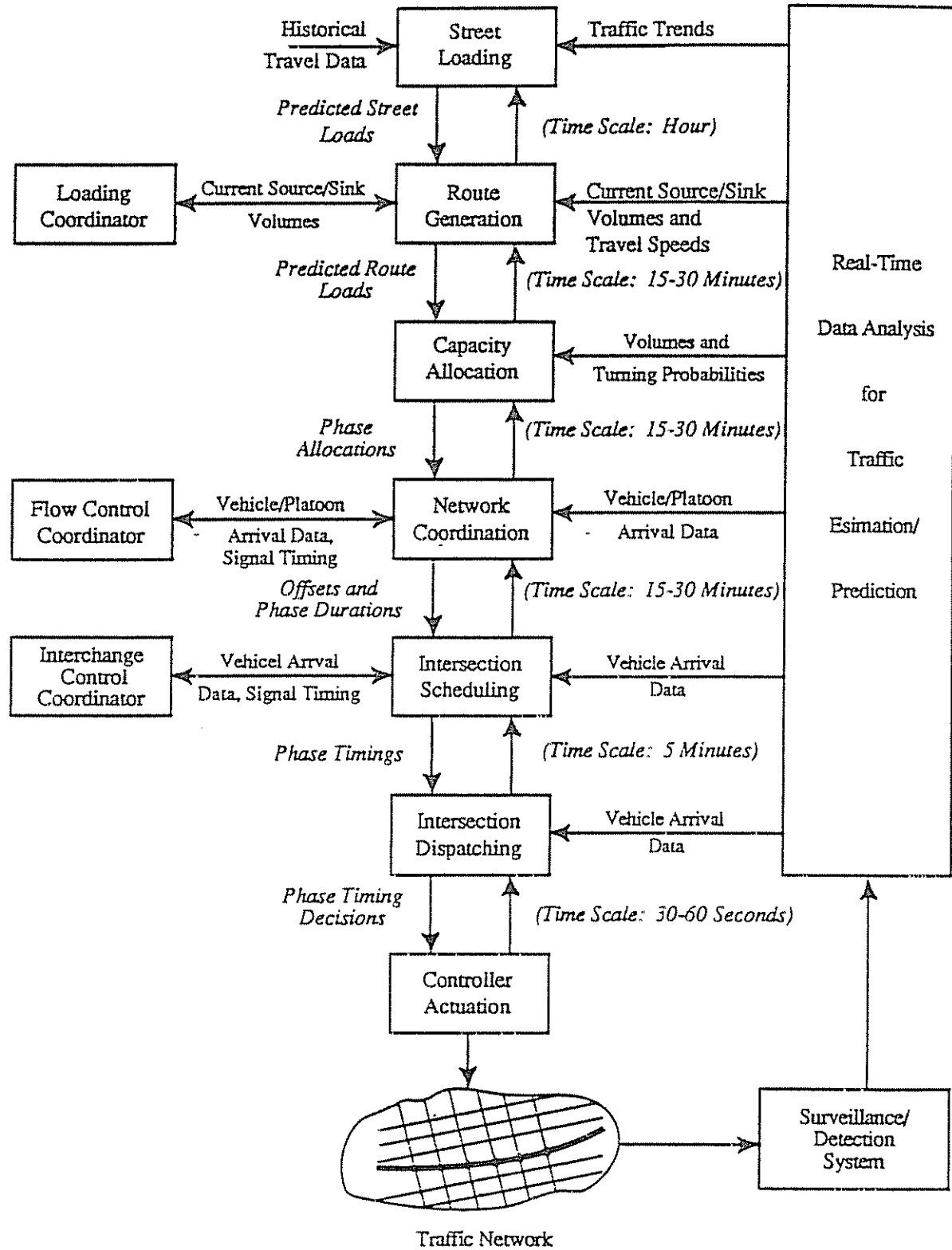


Figure III-3. Surface Street Hierarchical Control System Architecture.

The *capacity allocation* and *network coordination* components perform the network flow control function. The *capacity allocation* component determines the fraction of time that should be allocated to each phase at each intersection to meet the average travel demand over the next 15-30 minute time horizon. At this level the demand is expressed only in terms of average flow rate, such as number of vehicles per hour per lane, and not in terms of platoons of vehicles or individual vehicles. The (street) *network coordinator* component determines the signal timings by on-line optimization of movement of platoons. The optimization can be in terms of maximizing progression (as MAXBAND and PASSER do), or in minimizing stops, and/or delay (as TRANSYT does). The network coordinator determines the signal timings to meet the average traffic demand, as specified by the capacity allocation component, and does not necessarily respond to the individual vehicles.

The *intersection scheduler* and the *intersection dispatcher* perform the intersection control function. The *intersection scheduler* determines the sequence and duration of phases to be responsive to the actual observed traffic patterns that are evolving within the local intersection region. The decisions made at this level are constrained to remain within the *decision space* determined by the *network coordinator*, but are free to be responsive to the actual traffic within the intersection. For example, the network coordinator may decide when the main street and the side street through-movement phases should begin in order to allow platoon progression, but the intersection scheduler may choose a leading, a lagging or a skipped left turn phase. It may decide to have a phase with a single left turn and a single through movement at the same time. The purpose of the decisions at this level is to be responsive to the actual traffic demand, recognizing human factors considerations such as driver expectancy and reaction time.

The *intersection dispatcher* takes the optimal traffic flow decisions from the *intersection scheduler* and modifies them to accommodate pedestrians, buses and/or emergency vehicles as well as last second observations in the actual traffic arrival patterns.

III.2 Real-time Traffic-adaptive Freeway Control Architecture

The hierarchical control architecture for the freeway control system (FCS) is shown in Figure II-4. The architecture is analogous to that of the (surface) street control system. The current flow controls that are available for freeways are speed and lane controls, as opposed to the conventional traffic signals available for street networks.

At the highest level is the *freeway loading* and the *route generation* components. The *freeway loading* component uses historical travel data and observed traffic trends to predict the demand on the freeway over the next hour. These loads are input to the route generation component where routes over the next 15-30 minutes are determined using current source/sink volumes and travel speeds, as well as information from the surface street sources and sinks. As in the street control system, if appropriate IVHS technologies are available, the *route generation* component can issue route advisories to vehicles on the freeway informing them of incidents and excessive congestion.

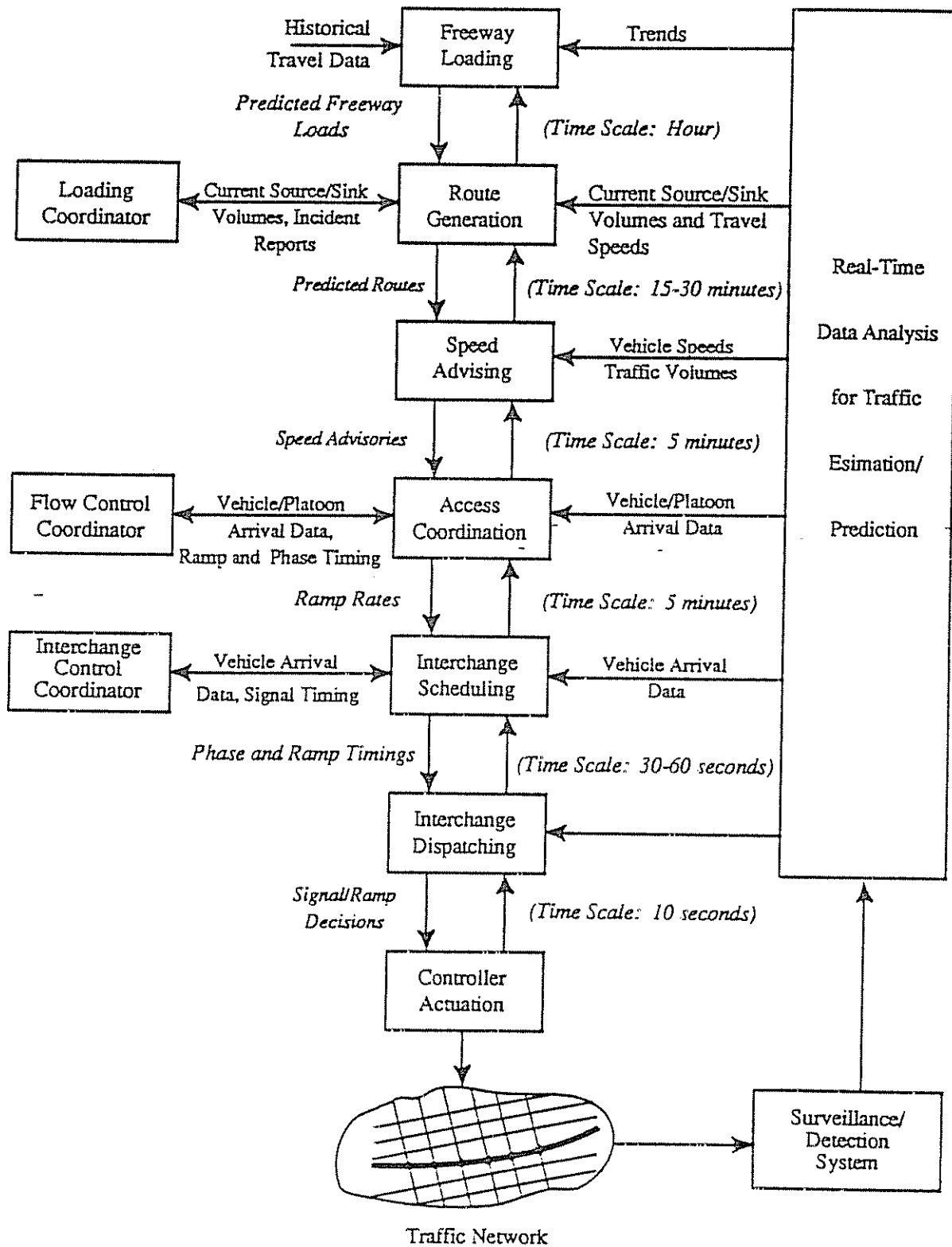


Figure III-4. Freeway Hierarchical Control System Architecture.

The flow control function is performed by the *speed advisory* and the *access coordinator* components. The goal of the flow control function is to provide smooth flow along the freeway. Difficulties in maintaining a smooth flow are due to different flow rates and densities in adjacent segments of freeway. This difference results from entering and exiting volumes, as well as weaving, that produce "shock waves" which effect smooth traffic flow. One method to limit the effect of these shock waves is to advise drivers to reduce speed before they reach a segment of freeway that is more congested. Another control method is to limit the access of vehicles to congested segments, and other upstream segments, to avoid the shock wave effect. The *speed advising* and the *access coordination* components perform these functions.

The *interchange scheduler* and the *intersection dispatcher* are responsible for the local freeway control function. A freeway interchange can consist of ramp meters and traffic signals or only ramp meters. The interchange scheduler is responsible for determining the signal phase change epochs, the phase durations and the ramp metering rates at each freeway/street interchange. The main purposes of ramp meters have been to smooth the platoon characteristics of surface street traffic into a smooth continuous flow that can be effectively integrated into the freeway flow and to limit the access to the freeway to help maintain smooth freeway flow. In heavily congested conditions, the ramp metering rate may not be sufficient to effectively discard the demand from the surface streets and, therefore, long queues and grid lock can occur on the surface street networks. A tradeoff must be made between smooth freeway flow and street congestion. Obviously, when both the freeway and the streets are heavily congested only efficient management of the high traffic volumes and queues is possible. When they are not congested, traffic may be both efficiently managed and made to flow "smoothly". The interchange scheduler is responsible for controlling the freeway/street interface and maintaining a "fair" tradeoff between the two systems, with regard to traffic management and control.

The role of the *interchange dispatcher* is similar to that of the *intersection dispatcher* in the street control system. The *interchange dispatcher* is responsible for providing priority to HOV, transit and emergency vehicles, accommodating pedestrians, etc.

III.3 Control Coordinator Architecture

The control system coordinator is responsible for ensuring proper communication and coordination between the freeway control system (FCS) and the street control system (SCS). The control coordinator can be either passive or active control. As a passive control element of the ITMS, the coordinator is only responsible for providing communication channels between the two systems. At the loading level a passive coordinator will treat the interface between the two systems as sources and sinks. For example, a sink for the street loading model will be a source for the freeway loading model. At the flow control level the passive coordination consideration depends on whether the interchange traffic control signals are controlled by FCS or SCS. If the signal is part of the FCS, then the surrounding street traffic control signals must be aware of its signal timings to allow proper coordination. If it is part of the SCS then the signal timings must be provided to FCS to determine appropriate ramp metering rates.

In an active control coordinator the two systems work together to achieve a common goal of efficient and effective control for the entire integrated freeway/street system. At the loading level, a single integrated network loading model, that predicts routes and loads which utilize both the freeway and the surface streets must be used. Utilization of a single model is more realistic. Travelers plan trips that use both freeways and surface streets to achieve the best level of service. The route generation components will operate by sharing information and advisories. Travel advisories on the surface streets may advise drivers to avoid the freeway due to heavy congestion, or may advise freeway travelers to use access roads or adjacent arterials. The role of the coordinator is to distribute the travel demand so that the best overall level of service can be achieved.

Relatively little coordination is required at the flow control level. Except for the distribution of travel demand, the interaction between the flows on the two traffic systems is primarily at the interchanges. The coordination of the interchanges can be accomplished at the intersection/interchange level where signal timing and ramp metering decisions can be concurrently made, with consideration of access coordination and network coordination control decisions. At intersections where no ramp meters exist, the control coordinator considers only the intersection scheduler and dispatcher decisions and freeway on/off ramp volumes.

III.4 The RHODES Research Project

For the past 15 months, since June 1, 1991, the Arizona Department of Transportation has supported the R&D efforts on the development of the RHODES street traffic control system within the Department of Systems and Industrial Engineering at the University of Arizona. PHASE I of this effort has been completed and PHASE II(a) is currently in progress. During these phases the University of Arizona has worked closely with the City of Tucson and the Pima Association of Governments (PAG) in the development of the RHODES concept, some preliminary algorithms, and a simulation model.

PHASE I of the RHODES project consisted of the following tasks:

- Task 1(a): Develop RHODES concept
- Task 1(b): Develop analysis/simulation tools
- Task 1(c): Select demonstration test grid
- Task 1(d): Hold traffic control workshop

- Task 2(a): Refine RHODES concepts
- Task 2(b): Investigate flow optimization models
- Task 2(c): Investigate intersection dispatching schemes
- Task 2(d): Coordinate modeling efforts.

Tasks 1(a) and 2(a) concentrated on developing a technically sound concept for real-time traffic adaptive control and identifying the key research problems that need to be solved. Task 1(b) consisted of specifying the requirements for a simulation model for demonstrating, testing and evaluating real-time control. It was decided, at least for the short term, that modification of the TRAF-NETSIM model would provide a suitable simulation environment. In the longer term, more advanced simulation models that allow dynamic vehicle routing and have the

ability to assess ATIS and other IVHS technologies would be more appropriate. To this end, an investigation of object oriented traffic simulation has been initiated.

Task 1(c) addressed the long-term project goal of implementing RHODES for the Tucson street network. A potential test grid has been selected. The test grid offers several interesting traffic characteristics, such as having a variety of traffic volumes, and a mix of residential and commercial zones. Early selection of the test grid provides a source of real-world data for the traffic simulations and a measure against which to validate the developed simulation model.

Task 1(d) provided a forum of noted experts on real-time traffic control to discuss research issues and comment on the RHODES concept. The workshop was very valuable to the research team. It led to the refinement of the RHODES concept and identified several new key issues.

Tasks 2(b) and (c) focused on the investigation and development of some preliminary algorithms for intersection and network flow control. An algorithm was developed, called COP, based on a dynamic programming formulation of the intersection control problem. The COP algorithm provides the necessary planning horizon, approximately 5 minutes, for integration with network flow control methods.

In addition to these tasks, a major goal of PHASE I was the development of a proposal to FHWA on the design of a real-time traffic-adaptive signal control system. The RHODES team led a strong consortium, that included JHK, SRI, TASC, RPI, and Hughes, and submitted a consortium proposal to FHWA in January 1992. The proposal was not selected for funding; the contract was awarded to Farradyne Systems in June 1992. However, the RHODES team plans to respond to an anticipated FHWA-RFP that will call for alternative prototype developments.

Phase II(a) is currently concentrating on (1) the development of some RHODES component models and algorithms and (2) a demonstration of these algorithms, using the modified TRAF-NETSIM simulation model. PHASE II(a) consists of three tasks:

- Task A: Develop algorithms for network loading and control
- Task B: Demonstrate controller interface and network control concepts
- Task C: Reporting and planning

Task A addresses the investigation and development of algorithms at several levels of the hierarchy as identified in PHASE I. The purpose of Task B is to demonstrate the proof of concept that the RHODES approach can be implemented using existing controller technology.

Together with technical and final reports, this proposal is a product of Task C. In addition, in Phase II(a) the RHODES team participated in responding to two other FHWA-RFPs. One of these proposals is on the development of Support Systems for an ATMS Control Center; the other is on the development of traffic simulation models for testing real-time traffic-adaptive control systems; the other (in which the RHODES team is a subcontractor in LORAL AeroSys) is on the design of ATMS Support Systems. The first proposal was not selected for

funding, the contract was awarded to KLD & Associates. The second proposal was selected for award and the contract is underway.

The research progress on the RHODES project has been significant. A simulation model has been developed for testing and demonstrating real-time traffic control algorithms, and several algorithms have been developed. Concurrently with the further development of the RHODES system for street network control, it is now appropriate to extend the RHODES concept for developing a traffic control system for an integrated freeway/street network.

IV. PROPOSED ITMS WORKPLAN AND SCHEDULE FOR FULL SCOPE

IV.1 Full Scope of Work

In this section, a specific task-by-task project workplan is proposed for a 16 month period to carry out the full scope of work. These task will be divided into two stages, stage 1 and stage 2, with the task logically allocated to each stage. The goals of the proposed project, which we refer to as *RHODES ITMS*, are to continue the development of *RHODES* for street networks, and to enhance the *RHODES* design to an ITMS for freeway/street networks. Section III of this proposal discusses the conceptual design for our ITMS. For brevity, we shall refer to our SCS and FCS subsystems as *RHODES-SCS* and *RHODES-FCS* and the integrated system as *RHODES-ITMS*.

The overall program scope calls for:

- (1) ITMS algorithm/model development, laboratory testing and field testing,
- (2) development of proposal(s) for IVHS research and demonstration project(s), and
- (3) the active participation in national IVHS research committees and meetings.

The ITMS algorithm/model development effort includes the scientific research that is required for the development of a real-time traffic-adaptive control system for an integrated freeway/street system. The effort also includes the laboratory and field testing of the developed algorithms/models.

The development of proposals for IVHS demonstration project(s) represents the effort to attract FHWA funds for the field demonstration of the ITMS system. In addition, it is anticipated that the University of Arizona, and others (City of Tucson, ATRC, ADOT, and ASU), will be responding to requests for proposals (RFPs) for other IVHS projects during this research Program. For example, the University of Arizona *RHODES* research team has been the prime responder on two FHWA proposals, for (1) the development of a real-time traffic-adaptive signal control system and (2) the development of traffic models for testing real-time traffic-adaptive signal control logic. It has also been a key consortium member on a FHWA contract for the design of ATMS Support Systems, with LORAL AeroSys as the prime responder. Participation in national IVHS research committees and meetings is essential for both, (i) keeping abreast of IVHS research and deployment activities and (ii) attracting research funds. Most of the current FHWA sponsored IVHS projects interface with one another and the national committees and meetings are a natural forum for sharing research results and experience.

Briefly, the general approach proposed for the development of the ITMS models/algorithms is as follows:

- (1) Develop (or investigate) component models at each hierarchical level;
- (2) Demonstrate/evaluate each component using a simulation model;

- (3) Integrate component models (by hierarchical level);
- (4) Demonstrate/evaluate integrated subsystems using a simulation model;
- (5) For each hierarchical level, develop control coordinator between SCS and FCS;
- (6) Demonstrate/evaluate coordinated SCS and FCS subsystems using a simulation model;
- (7) Laboratory test and evaluate an overall (integrated/coordinated) ITMS system using a simulation model; and
- (8) Field test and evaluate the ITMS system.

The first step in this process involves the development of individual component models for each hierarchical level, for both the SCS and the FCS. For example, the intersection dispatcher and interchange dispatcher are component models for SCS and FCS, respectively. These models are demonstrated and evaluated in step 2. In step 3, the component models are hierarchically integrated. For example, in SCS, the intersection scheduler and the intersection dispatcher are integrated in step 3 and then tested in step 4. In step 5, the component models at the respective hierarchical levels within SCS and FCS are horizontally integrated -- that is, via the control coordinator. For example, the intersection controller (comprising of the intersection scheduler and intersection dispatcher), and the interchange controller (comprising of the interchange scheduler and the interchange dispatcher), are horizontally integrated in step 5; the integration is demonstrated and evaluated in step 6. This process is repeated, each time a new layer is added to the hierarchy and then horizontally integrated via the coordinator. In step 7, the entire hierarchical ITMS is developed and tested using simulation models. Finally, in step 8, the ITMS is installed, tested and evaluated in the field.

This approach to the overall system development supports both (1) the desirability of a modular ITMS and (2) the deliverability of results (on a subsystem design and performance) through the duration of the program. It is possible, based on the hierarchical modularity, to actually implement a hierarchical layer at a time since a priori default decisions from the higher layers may be implemented based on time-of-day conditions, in the case of flow control, or calendar-day conditions, in the case of network loading.

Although the long-term goal of this research is to develop a complete ITMS, that includes all levels of the hierarchy conceptualized in Section III, this project will focus on: (i) the review of literature relating to freeway and integrated freeway/street traffic models and control methods, (ii) the development of simulation models to test real-time control, and (iii) the development of and the demonstrate of a real-time traffic-adaptive signal control subsystem (for the intersection/interchange level of hierarchy).

The following tasks will be completed in this design and development effort:

- A. Literature Review
- B. Develop Simulation Models
- C. Develop Intersection/Interchange Control Models
- D. Develop Flow Control Models
- E. Integrate Hierarchical Control Models
- F. Laboratory Test
- G. IVHS R&D Liaison.

These tasks are described in the next subsection. The schedule and deliverables are given in subsection IV.3. The project management, research team and the participating agencies are detailed in subsection IV.4.

IV.2 Project Tasks for Full Scope of Work

Task A: Literature Review

The purpose of this task is to review the literature on traffic models and control algorithms for freeways and integrated street/freeway networks. Our current understanding is that very little work has been reported on traffic models and control algorithms for an integrated freeway/street network. Nevertheless, a thorough literature review is necessary to ascertain the current state of the art and the state of practice. The following four subtasks are included in Task A:

- A.1 Review Freeway Traffic Models
- A.2 Review Freeway Control Algorithms
- A.3 Review Integrated Street/Freeway Traffic Models
- A.4 Review Integrated Street/Freeway Control Algorithms

This task will result in a working paper reporting existing freeway traffic models, freeway control algorithms, and integrated freeway/street traffic models and control algorithms.

Approach

In Task A.1 we will

- identify, from the literature, existing freeway traffic models including mathematical models, macroscopic simulation models and microscopic simulation models,
- determine the data requirements (inputs) for each model in order to build a working simulation model,
- identify which traffic features and characteristics (e.g. HOV lanes, ramp metering, route assignment, lane controls and speed controls) may be included in each model,
- identify the performance measures (MOE's) that may be obtained from each model,

- identify, for the simulation models, the computer/computation requirements, and
- determine if the model can be interfaced with an external real-time traffic-adaptive control logic, or if the model source code is available and if it is feasible to modify the source code for evaluating real-time traffic-adaptive control logic.

In this Task A.2 we will

- identify existing freeway control methods including ramp metering, the use of variable message signs (VMS), speed controls, and lane controls,
- investigate freeway control algorithms including simple metering, demand responsive metering, gap-acceptance metering, and pacer and greenband systems (e.g. Caltrans District 7 uses a software system called SATMS on their ModCom computer that supports system wide, traffic responsive and real-time modes of operation, but they do not utilize this feature due to the calibration required to make it operate effectively), and
- identify the performance indices (MOE's) that are optimized in these algorithms.

In this Task A.3 we will

- identify, from the literature, integrated street/freeway traffic models including both mathematical and computer simulation models,
- determine the data requirements (inputs) for each model in order to build a working simulation model,
- identify which traffic features and characteristics (e.g. HOV lanes, ramp metering, integrated route assignment, lane controls, speed controls, integrated ramp meter and adjacent intersection control, and surface street signal control) may be included in each model
- identify the performance measures (MOE's) that may be obtained from each model,
- identify, for the simulation models, the computer/computation requirements, and
- determine if the model can be interfaced with an external real-time traffic-adaptive control logic, or if the model source code is available and if it is feasible to modify the source code for evaluating real-time traffic-adaptive control logic.

In this Task A.4 we will

- identify existing integrated freeway/surface street control algorithms including ramp metering, variable message signs (VMS), speed controls, lane controls, and corridor progression (both surface street and freeways),
- investigate integrated freeway/surface street control algorithms if any are available or reported in the literature, and
- identify the performance indices (MOE's) that are optimized in these algorithms.

Task B: Develop Simulation Models

Simulation models play an important role in the development of a real-time traffic-adaptive control system. Simulation models will be used to test and evaluate algorithms, to generate data for modeling purposes, and to demonstrate component models and subsystems. Important issues in the selection and/or design of simulation models for this project include (1) the accuracy of the simulation models, (2) the ability of the models to simulate real-time control as specified by our hierarchical control system, (3) the ability of the simulation models to represent different traffic network characteristics and (4) the measures of effectiveness that the simulation models can provide.

It is important that the selected and/or developed simulation model be able to represent an integrated freeway/street traffic system. To our knowledge, the only integrated simulation model that will be readily available is the CORFLO model that FHWA has recently released. The RHODES research team has an advance copy of CORFLO and will evaluate its ability to meet the simulation model requirements of this project.

Our experience with the TRAF-NETSIM model in the current phase of the RHODES project has shown that it can be modified to meet the needs of developing and/or testing real-time traffic control algorithms for street networks. To evaluate available models, and to develop new or enhance available models to meet the needs of the project, the following subtasks are proposed:

- B.1 Evaluate Existing Freeway Simulation Models
- B.2 Develop/Enhance Freeway Simulation Models
- B.3 Evaluate/Develop/Enhance Integrated Simulation Model
- B.4 Perform HOV Case Study using Simulation Model

Throughout this task, specific modeling requirements will be developed for the I-17 corridor. The I-17 corridor, (shown in Exhibit II-1) geometrics and traffic characteristics will be used to develop the data base for the freeway simulation and the integrated freeway/surface street simulation models.

The product of this task will be a technical report summarizing the results of the evaluations and the development of the simulation models. The initial modification and/or development of the simulation models will be for the purpose of evaluating the intersection/interchange controllers developed in Task C and to demonstrate/evaluate the network coordination and integrated flow models developed in Task E.

Approach

In Task B.1 we will:

- identify the characteristics that the simulation model must have to allow real-time traffic-adaptive freeway control. These characteristics include the ability to effect freeway traffic flow through real-time traffic-adaptive ramp metering, speed control, lane controls, etc., and the ability to obtain real-time traffic surveillance data. In addition, special network characteristics (such as frontage roads) and special traffic regulations (such as HOV lanes) that exist within the I-17 corridor will be identified,
- match these characteristics to those that may be simulated within existing freeway models,
- identify the deficiencies in each model and determine whether and how these deficiencies can be eliminated by enhancements of the simulation model, and
- select the "best" simulation model for the purposes of this project.

In Task B.2 we will:

- implement modifications to the selected simulation model to address the deficiencies,
- develop a data base for the I-17 freeway for the selected simulation model, and
- test and validate the modified freeway simulation model.

In Task B.3 we will:

- evaluate existing corridor simulation models (currently, only two corridor simulation models exist: CORFLO and INTEGRATION. These models will be evaluated to determine if they meet the requirement of interfacing with external real-time traffic-adaptive control logic),
- select a simulation model, based on the evaluation, and develop the data base for the I-17 corridor, and
- enhance the selected simulation model to allow the interface with and evaluation of the external control logic (these modifications/enhancements will primarily support the control algorithms developed in this effort, but anticipated future developments, such as wide area flow control and route advisement via ATIS will also be considered).

In Task B.4 we will:

- use the selected freeway and/or corridor simulation model to study the effect of implementing HOV lanes in the I-17 corridor,
- identify measures of effectiveness (MOE's) that reflect ADOT's requirements for HOV facilities,
- develop the appropriate simulation model data bases for the comparison studies,
- design a statistical experiment, including variance reduction measures, for determining the effectiveness of the HOV lanes and to identify what system parameters are most sensitive to HOV performance, and
- perform the statistical experiment and analyze the results of the experiment.

Task C: Develop Intersection/Interchange Control Models

This task will focus on the investigation and development of the interchange dispatcher, the interchange scheduler, and the intersection/interchange coordinator. This task will use the results of the current RHODES effort on intersection dispatching and scheduling for the development of the algorithms required at this level. Three subtasks proposed are:

- C.1 Investigate/Develop Interchange Scheduler (FCS)
- C.2 Investigate/Develop Interchange Dispatcher (FCS)
- C.3 Develop Model for Intersection/Interchange Control Coordinator (ITMS).

The freeway interchange control, including the scheduler and the dispatcher, will address the local control needs of an interchange. Figure IV-1 shows a typical interchange. This interchange consists of two street intersections, one on each side of the freeway, and the two ramp meters. The control decisions for the interchange controller include the signal phase sequence and timings of the two intersections, as well as the associated ramp metering rates. The objective of the interchange control differs from that of a street intersection control. In a street intersection control the objective is to minimize stops or delay, or a combination based on the level of congestion. The objective of interchange control will also address the desire to minimize stops and/or delay, but it is also concerned with management of queues at the ramp meters.

The coordination between interchanges and intersections is important when there is an intersection located near an interchange. For example, in the I-17 corridor, intersections on 27th Avenue are located 1/4 mile from the interchanges at I-17 and Dunlap, Northern, Glendale, Bethany Home, Camelback, Indian School and Thomas. Due to this close proximity, it is possible that queues at the interchange may effect the traffic at the intersection and vice versa. For coordinated control, the intersection control will be constrained, by the intersection/interchange control coordinator, in the phase sequence and phase durations to accommodate the traffic demand at the interchange.

The products of this task will be a technical report detailing each of the component models. In addition, the results of the demonstrations and evaluations of subtasks E.1, E.2, and F.1 will be included in the technical report.

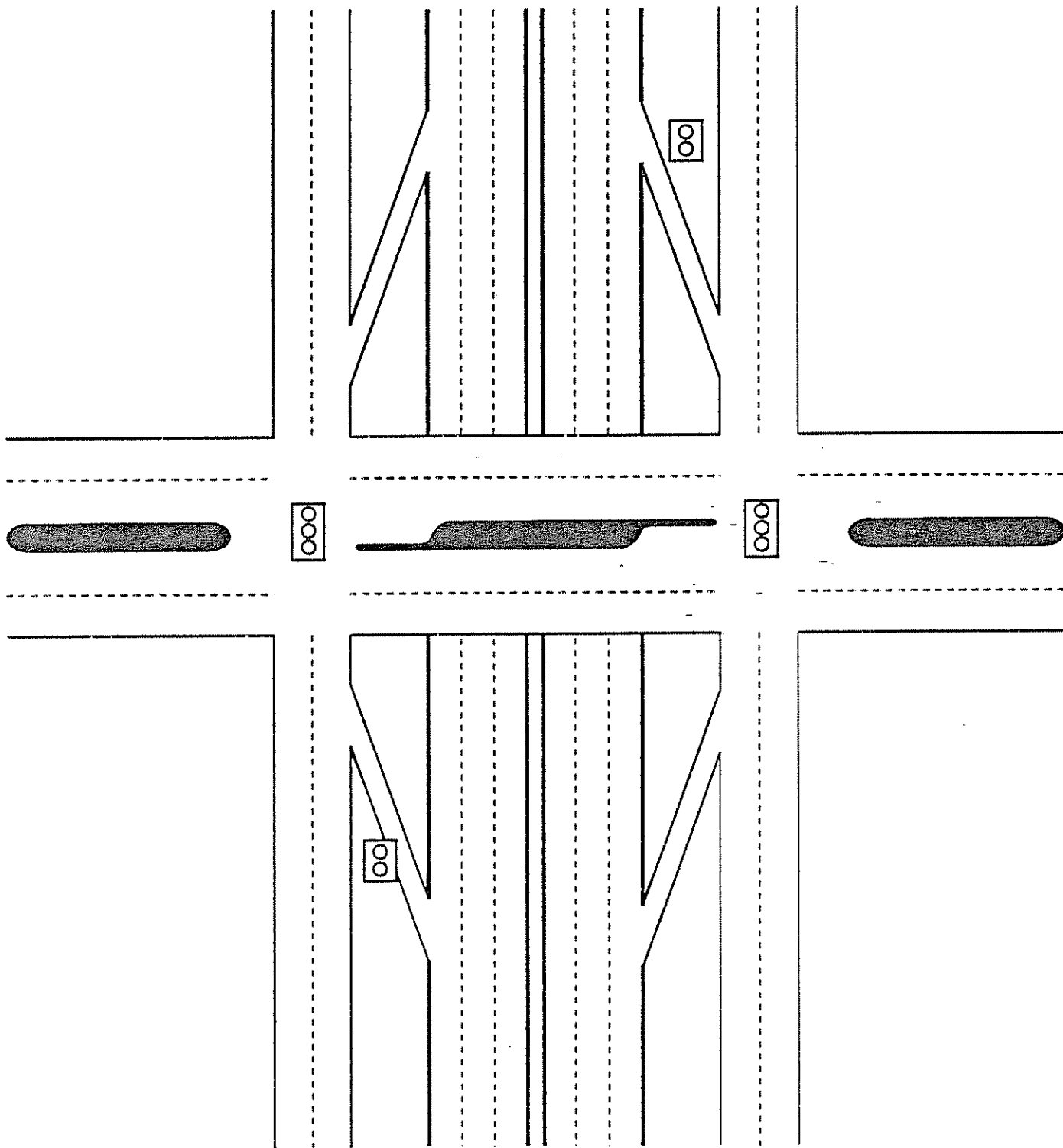


Figure IV-1. Typical interchange showing the freeway, frontage roads, and cross-street with traffic signals and ramp meters.

Approach

In Task C.1 we will:

- investigate and develop an interchange traffic flow model,
- develop a method for estimating interchange flows based on vehicle detection (it will be assumed that only existing detection equipment may be used, but additional detection may be implemented if it can be shown that sufficient benefits can be achieved with additional detectorization), and
- develop an interchange scheduler algorithm using the interchange traffic flow model and traffic flow estimator.

In Task C.2 we will:

- develop the interchange dispatcher for adjusting the interchange scheduler's timing decisions to the actual observed traffic patterns including pedestrian calls and emergency vehicle preemptions.

In Task C.3 we will:

- develop the intersection/interchange control coordinator to be used both (1) as an active control coordinator, constraining the intersection control algorithms and the ramp metering decisions, and (2) as a communication coordinator distributing information to local, regional and central control units.

Task D: Develop Flow Control Models

This task will address the development of the SCS network coordination model and will be the continuation of a current task. This task consists of a single subtask:

D.1 Investigate/Develop Network Coordination Model (SCS)

The products of this task will be a technical report detailing the network coordination model. In addition, the results of the demonstrations and evaluations of subtasks E.3, E.4 and F.1 will be included in the technical report.

Approach

In Task D.1 we will:

- investigate and develop the network coordination model for the control of a network of a surface street intersections. This effort will be tailored to address the particular geometric structure of the I-17 corridor and the City of Phoenix's desire for progression along the major arterials. In particular, we will address how to interface the cross streets and the freeway interchanges for progression along the

major arterials parallel to the freeway to provide real-time traffic-adaptive flow along the corridor.

Task E. Integrate Hierarchical Control Models

This task focuses on the integration and demonstration of the component models developed in the previously described tasks. This task consist of the following four subtasks:

- E.1 Integrate/Demonstrate Interchange Scheduling and Dispatching Models (FCS)
- E.2 Integrate/Demonstrate Intersection/Interchange Control Models (ITMS)
- E.3 Integrate Capacity Allocation and Network Coordination Models (SCS)
- E.4 Integrate/Demonstrate Network Flow and Intersection Control Models (SCS)

The products of this task are the integrated models. The results of the demonstrations will be included in the technical reports provided in Tasks C and D.

A major issue in the integration of these component models is the architecture of the software/hardware system on which this real-time control system will be implemented. It is intended that this system will operate in a distributed fashion with coordination between the distributed processors being accomplished through a communication network and through the control algorithms at the various levels of the hierarchy. The software architecture must be designed to meet these processing and communication requirements. For example, each field processor, or controller, must maintain a data base that can be polled by the regional and central processors. Each processor must also execute its decision algorithms, and estimation/optimization routines, on appropriate time scales and with the available computer facility. In addition, necessary communication must be maintained among the field equipment, controllers, detectors, and the regional and central control processors.

Approach

In Task E.1 we will:

- design the communication protocol (message passing scheme) between the interchange scheduler and the interchange dispatcher, and
- integrate and implement the interchange scheduler and the interchange dispatcher on the simulation model.

In Task E.2 we will:

- design the communication protocol between the interchange controller, the interchange/intersection coordinator, and the intersection controller, and

- integrate and implement the interchange controller, interchange/intersection coordinator and the intersection controller on the simulation model.

In Task E.3 we will:

- design the communication protocol between the capacity allocation model and the network coordination model.

In Task E.4 we will:

- design the communication protocol between the network flow control model and the intersection control model,
- implement the network flow control and the intersection control models within the simulation, and
- demonstrate the integrated control models on the simulation of the I-17 corridor (including a portion of the surface street network).

F. Laboratory Test

This task focuses on the laboratory testing and evaluation of the component and integrated subsystem models. This task consists of a single subtask:

F.1 Evaluate Component Models

The evaluation results from this task will be included in the technical reports provided in Tasks C and D.

G. IVHS R&D Liaison.

The purpose of this task is to establish and maintain a working relationship with the professional community associated with IVHS, in general, and ATMS, in particular, and to develop proposals for the support of the R&D Program described in Section IV. This task consists of two subtasks

G.1 Interface with *TRB* and *IVHS America* Committees

G.2 Develop IVHS Proposal(s) for FHWA

Subtask G.1 includes the attendance and participation at national *TRB* and *IVHS America* meetings and committees. Subtask G.2 includes the continuous development of the R&D Program described in Section IV, by either responding or participating in responses to RFP's. In particular, this subtask includes responding to the anticipated RFP that FHWA will release for the development of a prototype real-time traffic-adaptive signal control system. This RFP is expected to be published in the later part of 1993. In addition, the research team will assist in the development of an IVHS corridor demonstration project proposal for the I-17 corridor. The ITMS concept presented in this proposal should play a major role in this proposal.

IV.3 Deliverables and Schedule

Deliverables

The products of this research will include:

- a series of working papers detailing efforts on the various tasks including:
 - a review of freeway and corridor models, both mathematical models and computer simulations,
 - a review and evaluation of freeway control methods and algorithms,
 - an evaluation of freeway and corridor simulation models in terms of their applicability to the laboratory evaluation of real-time traffic-adaptive control logic,
 - a case study report detailing the use of a freeway simulation model to evaluate the effectiveness of HOV lanes ,
 - the formulation and development of the "Interchange Scheduler", "Interchange Dispatcher" and the "Intersection/Interchange Control Coordinator" (these systems are explained in Section III),
 - the formulation and development of the "Network Coordinator" model,
 - a description of the demonstration of the integrated control models,
 - the results of the laboratory testing, including the test plan and a description of the test network (within the I-17 corridor),
- Enhanced freeway and enhanced integrated freeway/street simulation models¹.
- The data base and simulation package used to perform the freeway HOV lane case study.
- The algorithm and computer implementation of the interchange scheduler.
- The algorithm and computer implementation of the interchange dispatcher.

¹Currently the RHODES research team has been given permission, by the Federal Highway Administration, to use and modify the TRAF-NETSIM model. We will seek permission, from FHWA, to deliver a copy of the modified models to ADOT.

- The algorithm and computer implementation of the intersection/interchange coordinator.
- The algorithm and computer implementation of the network coordinator model.
- A demonstration, or series of demonstrations, illustrating the operation of the component models both operating independently and in an integrated fashion.
- a technical presentation of the models, algorithms, laboratory tests and the test results.

Schedule

Exhibit IV-2 shows the 16 month schedule by task.

[illegible]

IV.4 Project Management and Research Team

The principal investigator on the project will be Pitu B. Mirchandani, Director of the RHODES Research Program. He has the appropriate experience, expertise, and accomplishments in the technical and management areas to lead the team and bring the program to a successful completion. Currently, he is the Department Head of Systems and Industrial Engineering and is a Full Professor within its faculty as well as a Full Professor in the Electrical and Computer Engineering Department. In addition, he is currently heading the Center for Emerging Technologies in Transportation Engineering (CRET²E) at the University of Arizona.

He will be assisted by Larry Head, who will be the Project Manager for this Phase II (b) of the program. He is currently the co-principal investigator on the RHODES Project and has been involved on all aspects of the research, from conceptual design, to the development of control algorithms. He has a doctoral degree in Systems Engineering.

Other principal researchers on the project are William Reilly (of JHK & Associates) and Dennis Sheppard (Assistant Traffic Engineer, City of Tucson). William Reilly has an extensive track record in performance of major research efforts in Traffic Engineering. He is a recognized expert in the field of traffic flow and highway capacity. He will assist in the development of the freeway traffic model and the integrated freeway/streets traffic model.

Dennis Sheppard has been with the RHODES research team right from its inception. He has been a major contributor towards the conceptual design of RHODES. His insight and on-the-job traffic engineering experience has been very valuable in the development of control algorithms and controller interface design. Mr. Sheppard has been a pioneer in IVHS implementation, being one of the first to install a speed advisory system on an arterial.

The project will also support three half-time graduate assistants. It is anticipated that, under the supervision of Drs. Mirchandani and Head, their respective task assignments will be

- (1) Development/enhancement/demonstration freeway and integrated simulation models ,
- (2) Development/evaluation of interchange dispatcher and scheduler and the development of the control coordinator for that level, and
- (3) Development/evaluation of street and freeway flow control algorithms and the development of the control coordinator at this level.

The appropriate levels of efforts for the various tasks are given in Exhibit IV-3

To make the simulation models meaningful, and to make the developed real-time ITMS applicable to the State of Arizona and its metropolitan areas, it is important that the research team liaison closely with Arizona Department of

Transportation and local transportation agencies. For this purpose, an advisory committee consisting of individuals from ADOT, ATRC, and appropriate agencies within Phoenix, Tempe and Maricopa County will be formed. At the moment we envision the following individuals on this committee:

Larry Schofield (ATRC)
Sarath Joshua (ATRC)
Dan Powell (ADOT)
Jim Matteson (City of Phoenix)
Bill Bain (City of Phoenix)
Bill Snider (City of Phoenix)
Tom Buick (Maricopa County)
Jim Decker (City of Tempe)

Included are estimated levels of efforts required for future tasks for developing and laboratory testing a prototype ITMS (this excludes systems development (Task I), and field implementation (Task J) and testing (Task K)). These figures are included information purposes and to provide an idea of the program scope to potential sponsors.

Exhibit IV-3

| Task | | |
|---|---------------|------------------|
| | person-months | approx. cost |
| A. Literature Review | | |
| A.1 Review Freeway Traffic Models | 0.8 | \$6,400 |
| A.2 Review Freeway Control Algorithms | 0.8 | \$6,400 |
| A.3 Review Integrated Street/Freeway Traffic Models | 0.2 | \$1,600 |
| A.4 Review Integrated Street/Freeway Control Algorithms | 0.2 | \$1,600 |
| | | |
| B. Develop Simulation Models | | |
| B.1 Evaluate Existing Freeway Simulation Models | 3 | \$17,000 |
| B.2 Develop/Enhance Freeway Simulation Models | 6 | \$34,200 |
| B.3 Evaluate/Develop/Enhance Integrated Simulation Model | 6 | \$34,200 |
| B.4 Perform HOV Case Study | 6 | \$34,200 |
| | | |
| C. Develop Intersection/Interchange Control Models | | |
| C.1 Investigate/Develop Interchange Scheduler (FCS) | 7 | \$39,800 |
| C.2 Investigate/Develop Interchange Dispatcher (FCS) | 3.2 | \$18,200 |
| C.3 Develop Model for Intersection/Interchange Control Coordinator (ITMS) | 1.8 | \$10,200 |
| | | |
| D. Develop Flow Control Models | | |
| D.1 Investigate/Develop Network Coordination Model (SCS) | 6.4 | \$36,400 |
| | | |
| E. Integrate Hierarchical Control Models | | |
| E.1 Integrate/Demonstrate Interchange Scheduling and Dispatching Models (FCS) | 2 | \$11,400 |
| E.2 Integrate/Demonstrate Intersection/Interchange Control Models (ITMS) | 1.4 | \$8,000 |
| E.3 Integrate Capacity Allocation and Network Coordination Models (SCS) | 2.6 | \$14,200 |
| E.4 Integrate/Demonstrate Network Flow and Intersection Control Models (SCS) | 1.8 | \$10,200 |
| | | |
| F. Laboratory Test | | |
| F.1 Evaluate Component Models (effort included in Tasks B and E) | | |
| | | |
| G. IVHS R&D Liaison | | |
| G.1 Interface with TRB and IVHS America Committees | 0.8 | \$8,000 |
| G.2 Develop IVHS Proposal(s) for FHWA | 0.8 | \$8,000 |
| TOTAL | 50.8 | \$300,000 |

V. PROPOSED ITMS WORKPLAN AND SCHEDULE FOR STAGE 1 PROJECT

The full scope of the project as discussed in the previous section has been divided into a two stage project with each stage containing approximately half the full scope. The STAGE 1 project will be carried out as a separate project over a period of twelve months, with included a six week report review period. It is envisaged that the STAGE 1 project will be launched first with the STAGE 2 project undertaken at a later time when the funds become available. The results from STAGE 1 will be utilized in carrying out the STAGE 2 tasks.

V.1 Tasks for Stage 1 Project

Exhibit V-1 shows the tasks and level of effort required for executing each task in the STAGE 1 project.

V.2 Deliverables and Schedule

Exhibits V-2 and V-3 show the deliverables from the project and the planned schedule of project activities.

V.3 Budget

Exhibit V-4 shows a breakdown of the budget required for the project.

Exhibit V-1

| Task | Stage 1 | Stage 1 costs |
|---|---------------|------------------|
| | person-months | |
| A. Literature Review | | |
| A.1 Review Freeway Traffic Models | 0.8 | \$6,400 |
| A.2 Review Freeway Control Algorithms | 0.8 | \$6,400 |
| A.3 Review Integrated Street/Freeway Traffic Models | 0.2 | \$1,600 |
| A.4 Review Integrated Street/Freeway Control Algorithms | 0.2 | \$1,600 |
| | | |
| B. Develop Simulation Models | | |
| B.1 Evaluate Existing Freeway Simulation Models | 3 | \$17,000 |
| B.2 Develop/Enhance Freeway Simulation Models | 3 | \$17,000 |
| B.3 Evaluate/Develop/Enhance Integrated Simulation Model | 0 | |
| B.4 Perform HOV Case Study | 2.6 | \$12,400 |
| | | |
| C. Develop Intersection/Interchange Control Models | | |
| C.1 Investigate/Develop Interchange Scheduler (FCS) | 7 | \$39,800 |
| C.2 Investigate/Develop Interchange Dispatcher (FCS) | 3.2 | \$18,200 |
| C.3 Develop Model for Intersection/Interchange Control Coordinator (ITMS) | 1.8 | \$10,200 |
| | | |
| D. Develop Flow Control Models | | |
| D.1 Investigate/Develop Network Coordination Model (SCS) | | |
| | | |
| E. Integrate Hierarchical Control Models | | |
| E.1 Integrate/Demonstrate Interchange Scheduling and Dispatching Models (FCS) | 2 | \$11,400 |
| E.2 Integrate/Demonstrate Intersection/Interchange Control Models (ITMS) | | |
| E.3 Integrate Capacity Allocation and Network Coordination Models (SCS) | | |
| E.4 Integrate/Demonstrate Network Flow and Intersection Control Models (SCS) | | |
| | | |
| F. Laboratory Test | | |
| F.1 Evaluate Component Models (effort included in Tasks B and E) | | |
| | | |
| G. IVHS R&D Liaison | | |
| G.1 Interface with TRB and IVHS America Committees | 0.4 | \$4,000 |
| G.2 Develop IVHS Proposal(s) for FHWA | 0.4 | \$4,000 |
| TOTAL | 25.4 | \$150,000 |

EXHIBIT V-2

Deliverables for RHODES ITMS Stage-I

| | |
|---|--|
| Task A: Literature Review | <u>Literature Review Report</u> on Freeway and Integrated Surface Street/Freeway Control |
| Task B: Develop Simulation Models | <u>Working Paper</u> including: Reviewing and Evaluating Freeway and Integrated Simulation Models, Simulation Model for Evaluating HOV facilities, Requirements for Simulation Evaluation of Real-time Traffic-adaptive Integrated Signal Control Logic <u>Demonstration</u> of Simulation Models of Freeway/Surface Street Networks including a detailed model of the selected I-17 interchange and the HOV simulation study area. |
| Task C: Develop Interchange/Intersection Control Models | <u>Working Paper</u> describing the Interchange/Intersection Control Algorithms including Off-line Testing Results |
| Task E: Integrate Hierarchical Control Models | <u>Working Paper</u> describing the results of the Algorithm Integration and Simulation Evaluation of the Interchange/Intersection Control Algorithms |
| Task IG: IVHS R&D Liaison | <u>Submission</u> of technical papers for 1995 TRB or IVHS America Annual Meeting Assist ADOT in the preparation of a proposal for an IVHS Operational Test |
| Task IH Project Management | <u>Prepare and Submit</u> monthly and quarterly progress reports. <u>Attend</u> bi-monthly meeting with project committee to review progress |
| Stage I Final Report | Documentation of all of the accomplishments of the Stage I project including revised versions of the working papers from each of the above tasks. |

Exhibit V-3

| Task | Month | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|-------|---|---|---|---|---|---|---|---|---|----|----|----|
| 1.A. Literature Review | | | | | | | | | | | | | |
| 1.A.1 Review Freeway Traffic Models | | | | | | | | | | | | | |
| 1.A.2 Review Freeway Control Algorithms | | | | | | | | | | | | | |
| 1.A.3 Review Integrated Street/Freeway Traffic Models | | | | | | | | | | | | | |
| 1.A.4 Review Integrated Street/Freeway Control Algorithms | | | | | | | | | | | | | |
| 1.B. Develop Simulation Models | | | | | | | | | | | | | |
| 1.B.1 Evaluate Existing Freeway Simulation Models | | | | | | | | | | | | | |
| 1.B.2 Develop/Enhance Freeway Simulation Models | | | | | | | | | | | | | |
| 1.B.4 Perform I/OV Case Study | | | | | | | | | | | | | |
| 1.C. Develop Intersection/Interchange Control Models | | | | | | | | | | | | | |
| 1.C.1 Investigate/Develop Interchange Scheduler (FTC) | | | | | | | | | | | | | |
| 1.C.2 Investigate/Develop Interchange Dispatcher (FTC) | | | | | | | | | | | | | |
| 1.C.3 Develop Model for Intersection/Interchange Control Coordinator (ITMS) | | | | | | | | | | | | | |
| 1.E. Integrate Hierarchical Control Models | | | | | | | | | | | | | |
| 1.E.1 Integrate/Demonstrate Interchange Scheduling and Dispatching Models (FTC) | | | | | | | | | | | | | |
| 1.G. IVHS R&D Liaison | | | | | | | | | | | | | |
| 1.G.1 Interface with TRB and IVHS America Committees | | | | | | | | | | | | | |
| 1.G.2 Develop IVHS Proposal(s) for FHWA (as needed) | | | | | | | | | | | | | |
| 1.H. Project Management | | | | | | | | | | | | | |
| 1.I. STAGE 1 Final Report* | | | | | | | | | | | | | |
| 1.I.1 Prepare Draft Final Report | | | | | | | | | | | | | |
| 1.I.2 ADOT Review | | | | | | | | | | | | | |
| 1.I.3 Final Report | | | | | | | | | | | | | |

*The Draft Final Report will be produced in accordance with the requirements of the U.S. Department of Transportation Report DOT-TST-75-97, "Standards for the Preparation and Publication of DOT Scientific and Technical Reports". Five Copies of the report will be submitted to the ATRC.

A four week period for review of the Draft Final Report has been included in the project schedule.

The review comments will be addressed in the Final Report. One Camera ready original and five copies of the Final Report will be submitted to ATRC.

EXHIBIT V-4

| Budget for RHODES-ITMS Project - Stage 1 | | |
|---|---------|------------------|
| July 1, 1993- June 30, 1994 | | |
| Program Director, PI | | \$21,100 |
| Pitu Mirchandani (10% AY+summer) | | |
| Project Manager, Co-PI | | \$25,000 |
| Larry Head (40% CY) | | |
| Subtotal | | \$46,100 |
| Graduate Assistants | | |
| 2 students (half-time) | | \$42,220 |
| Admin. Assist./ Sec. (.2 FTE) | | \$4,000 |
| Total Direct Labor | | \$92,320 |
| ERE | | |
| Investigators(19.7%) | | \$9,080 |
| Students(1.3%) | | \$550 |
| Staff(24.5%) | | \$980 |
| Subtotal ERE | | \$10,610 |
| Travel | | \$3,700 |
| 7 person-trips to Maricopa County/ADOT/ATRC | \$700 | |
| IVHS/TRB Meetings (2 presenters) | \$3,000 | |
| Operations | | \$3,800 |
| Equipment | | \$10,000 |
| Consultants/Subcontracts | | |
| Bill Reilly (JHK) - 8% CY (w/ cost-share) | | \$10,000 |
| Total Direct | | \$130,430 |
| Indirect Costs (15%) | | \$19,560 |
| Grand Total | | \$149,990 |